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Final Report

DEVELOPMENT OF QUALITY ASSURANCE SPECIFICATION FOR BRIDGE PAINTING CONTRACT

Luh M. Chang

Machine Hsie

David Unkefer

PURDUE UNIVERSITY

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To: Vincent P. Drnevich
Joint Highway Research Project

July 29, 1992

From: Luh M. Chang, Research Associate
Joint Highway, Research Project

Project: HPR-1-89-27
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Attached is the Executive Summary of the Final Report of the JHRP Study titled "Development of Quality Assurance Specification for Bridge Painting Contracts." This report is authored by Professor Luh M. Chang, Mr. Machine Hsie, and Mr. David Unkefer.

The objectives of the study were accomplished. Many pitfalls impeding steel painting quality were unveiled. Meanwhile, many possible solutions are recommended. In addition, four quality acceptance plans were developed and incorporated into a step-by-step check lists and working charts. Finally, a new standard specification for bridge painting contracts is presented.

A full set of recommendations and conclusions detailing the results of this project has been included.

The Final Report has been forwarded for review and accepted by all sponsors as fulfilling the objectives of the study.

Sincerely,

Luh M. Chang
Research Associate

DISCLAIMER

Many competent men and women serve the painting industry; however, in this report, masculine pronouns are occasionally used in reference to engineers, technicians and other personnel. This convention is intended to avoid awkwardness in style and in no way reflects sexual bias on the part of the authors.

All reasonable care has been taken in the preparation of this Manual. However, the Federal Highway Administration can accept no responsibility for the consequences of any inaccuracy or omission. The Federal Highway Administration does not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered necessary to the object of this publication.

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16. Abstract

The existing INDOT's standard specification for steel bridge painting was written in early 1970's. Meanwhile, the painting specification is still a recipe type of specification. Therefore, the purpose of this research is to upgrade the specification and to develop a more quality assurance type of specification to assure the obtaining the required painting quality for INDOT.

The research unveils many pitfalls interfering with obtaining adequate quality for INDOT steel bridge painting. Many possible solutions are proposed. Quality acceptance plans were constructed and incorporated into step-by-step check lists and working charts.

Finally, the existing specification for steel bridge painting was revised and an upgraded specification is presented.

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Chapter 1

Introduction

1.1 The Needs of the Research

To assure that the Indiana Department of Transportation (INDOT) receives a properly painted bridge with an expected period of service life from its contractors, a level of high quality needs to be maintained. INDOT is now using a recipe type of specification to control the quality for bridge painting. This type of specification includes details such as: what materials should be used, how the surface should be prepared, how the paints should be applied, etc (Indiana, 1988). Inspections of materials and work are required at various stages of painting and at the completion of the painting, before acceptance. With the many variables involved in the painting process, the current specification does not always guarantee the quality of the final painting product. Painting quality could be better assured by allowing the contractors to control more of their operation, by INDOT placing its emphasis on specifying and checking the end-results. That is, the contractors would take more responsibility for quality process control, and the INDOT would assume the responsibility for specifying the quality requirements, the acceptance criterion, and by inspecting the

product. This type of specification, with better allocation of the responsibility between owners and contractors, is designated Quality Assurance (QA) or End-Result Specification.

1.2 The Objectives of the Research

The purpose of this research is to develop a QA specification for steel bridge painting constructions. The specification should be able to ascertain the quality the painting that is necessary to perform its intended function. For this goal, the following procedures need to be completed.

To Review Current Practices

Current bridge painting practices, Indiana current regulations as well as other states' policies and existing inspection procedures, need to be reviewed. The pitfalls that interfere with the maintenance of painting quality should be investigated in order to establish an efficient inspection procedure.

To Determine Quality Parameters

Parameters determining the painting quality should be examined. These parameters need to be incorporated into the specification.

To Set Up Reasonable Quality Requirements

Proper quality requirements need to be identified to make the specification respectable and acceptable. Requirements that are too

vague can result in an ineffective protective coating. Conversely requirements that are too rigid can raise the cost of painting a bridge and make some specifications non-achievable.

To Establish An Efficient Acceptance Procedure

After the job is completed, there should be defined testing processes to determine acceptance. Statistical sampling methods should be applied to specify the inspection points, inspection periods, and the acceptance/rejection decisions.

To Develop QA Specification for Bridge Contracts

Finally, a quality assurance specification including the whole quality assurance system for the painting contract, should be developed. The existing specification should be revised to include such material. The possible solutions to the existing pitfalls should be proposed. The step-by-step inspection processes will give a precise guidance to the INDOT inspector's daily practices.

1.3 The Scope of the Research

The current INDOT's standard specification written, in the early 1970's, is inadequate to ensure the quality of the current painting construction. The specification, a guide to the inspectors' practice, does not specify: 1) where to take measurements; 2) how many measurements are needed to make acceptance decisions; and 3) what quality level is acceptable. As a result, the inspections are largely based on the inspectors'

personal judgements, thus making the acceptance or rejection of the project based on an ambiguously-defined inspection process. To solve these problems, the Statistical Sampling Method, the core of the QA specification, can be a powerful tool to specify a step-by-step guide for the inspectors. In this research, a systematic inspection procedure is derived to determine a course of action that will define the acceptance or rejection of the painting construction of the bridge.

A necessary step for determining quality requirements is to understand and assess the current practices. Therefore, existing quality data were collected, processed, and analyzed to support possible solutions to the problem of quality maintenance. Interviews with INDOT personnel, contractors, painters, and experts in both fields and shops were conducted to understand the problems from a qualitative perspective. State-of-the art of quality control and sampling methods were reviewed. Many documents from the Transportation Research Board (TRB) in the painting field were studied; additionally, the SSPC manual and video tapes, consisting of thorough instructions, were studied to obtain a comprehensive knowledge in painting construction. Several books and journals in both quality control and painting industry were studied to link the knowledge between painting construction and statistical quality control. In addition, the specifications from seven states and the Steel Structure Painting Council (SSPC) were reviewed. These methods provided a starting point for the assessment of current practices.

After the above knowledge was obtained, four acceptance sampling methods were developed. By combining the quality parameters, sampling methods, and stratified random sampling schemes, a checklist was developed, tried and revised. Following the sampling plan, inspectors could take a specific number of measurements on certain areas. Once the results of the measurements are applied to the formula of sampling plans, the acceptance or rejection decisions can be made. Additionally, in light of SSPC and other DOTs' experiences, the painting specification in Indiana 1988 (Indiana, 1988) was revised. A more reasonable specification is proposed.

Another advantage of the statistical sampling method is that it supplies an approach to adjustable pay schedules (Willenbrock, H. Jack 1977). A second degree adjustable pay schedule function curve, controlled by three points, was developed. This innovative pay schedule function makes the adjustable pay schedule more acceptable.

1.4 Limitation of the Research

At the current stage, the goal of a QA system aimed at the total end-result specification cannot be achieved. In the process of painting, many check points such as traffic control, ambient conditions, and paint mixtures need to be periodically inspected. Also, because visual inspection is still indispensable, the quality parameters in the acceptance plans still consist of a certain degree of subjective judgement. Furthermore, the application of the

proposed plans is limited to simple span steel bridges, because the researchers did not have a chance to access other types of bridges, except for the one truss bridge in the pilot study phase.

1.5 Structure and Content of the Report

This report has been divided into four major parts, each chapter to reflect a major subject areas.

Part I: Introduction\Background

Chapter 1 provides a general introduction that addresses the need for the research and its objectives. This is followed by the scope of what has already been done in the research. The limitations of the research are also mentioned. Chapter 2 is a brief introduction that provides information about corrosion problems, painting quality parameters, and the current QA programs. Part I ends with Chapter 3, which explains the research methodology in terms of three chronological phases.

Part II: Results of the Data

Chapter 4 presents the findings from the interviews. The verification and the error resource in the data collection are described in Chapter 5. Data analyses, followed by several inferences, are discussed in Chapter 6.

Part III: Development of QA Systems

Chapter 7, presents four acceptance sampling methods and

analyzed their advantages and disadvantages to the special purpose of painting inspection are analyzed. Chapter 8 introduces the concepts of adjustable pay schedule. A second degree pay factor function is derived to make the adjustable pay schedule more acceptable. Chapter 9 discusses the revision of the specification based on the knowledge obtained in this research. Chapter 10 addresses the subject of the painting contractor certification program which is being conducted by the Steel Bridge Painting Council (SSPC).

Part IV: Finalization of the Report

In Chapter 11, the developed acceptance plan and quality parameters are incorporated into a set of check lists and control charts. The check lists and control charts have been tried in both shop and field to assure their feasibility. In conclusion, Chapter 12 summarize many findings and solutions about the pitfalls of the steel bridge painting quality. Additionally, the chapter recommends further research areas that may improve the steel bridge painting quality.

Chapter 2

Background

2.1 Corrosion Problems

For thousands of years, corrosion has been the most serious problem affecting steel structures. So far, it is well documented that corrosion is the result of an electrochemical process involving an anodic reaction in which the metal goes into solution as an ion, and a cathodic reaction takes place. Because of steel's tendency to return to its natural state, after it has been extracted from its ore, the steel reacts with its environment and corrodes. To sum up, the process of corrosion requires four elements including 1) an anode, 2) a cathode, 3) an electrolyte, and 4) a conductor (SSPC 1989, pp 3-9). Only when these four components are present simultaneously can corrosion take place. Preventive approaches such as protective coatings, and cathodic protection methods achieve the goal of corrosion protection by eliminating any of the above four required elements. Steel contains both anodes and cathodes due to grain boundaries, grain orientations, thermal treatments, surface roughness and strains. Also, steel serves as an efficient conductor, and atmospheric moisture functions as the electrolyte. Accordingly, corrosion is an ever-present danger to steel structures. For most steel

structures, paint is applied to prevent corrosion by isolating the steel surface from the atmospheric moisture.

Currently, painting steel bridges costs the state of Indiana a lot of money every year, and some of these painting jobs have been failing prematurely. As a result, the Indiana Department of Transportation (INDOT) cooperates with the Federal Highway Administration (FHWA) and Purdue University to generate a new Quality Assurance Specification for steel bridge painting. A systematic inspection procedure is required in the specification to determine a course of action which defines the acceptance or rejection of the painted products.

Painting steel bridges is very complicated in terms of the variety of materials, the cleaning techniques, the control of the environment, and the methods of application. During the actual process of painting, the contractors may wash down the steel with water and/or detergent first, and follow with the application of a solvent to remove any remaining grease. After this, contractors normally sand blast or clean the steel to remove rust, mill scale and old paint. At this point, there may be an environmental concern, because many of the bridges were painted with lead paint, which is being taken off the bridge and is now known to be a hazardous substance. The process and cost of the removal of the lead-pigmented paint, with its accompany cost, has become one of the most critical items in steel bridge maintenance (Peart, John, 1988). After the old paint is removed and the anchor profile is created on the steel surface, the primer is sprayed on the cleaned

steel. This is applied immediately after the blasting in order to get the primer on before any rusting occurs. The top coat then follows the primer and can be done sometime later, as long there is not too much delay. Delaying too long may allow the surface to become contaminated, thus requiring additional cleaning. Painting a new structure is similar, except that the blasting and priming are usually done under the more controlled conditions of a steel manufacture shop. Top coats are later applied in the field.

2.2 Summary of Painting Quality Parameters

After the specifications of different states were surveyed, the researchers interviewed highway personnel, fabricator shops and painting contractors. At the same time, the literature was reviewed. Using all of these, a comprehensive knowledge in terms of quality parameters was obtained, which is summarized as follows:

1). Application Equipment

Without proper equipment, the quality of the painting products will be inadequately controlled. Important check points of the equipments such as air pressure, air cleanliness, containers, and abrasive are critical to maintain the quality of the painting.

2). Paint Material

Paint material largely and directly influences the performance of the corrosion protection function. Information such as

technical data sheets, shelf life, pot life, and batch numbers should be obtained to verify whether the used material is under its workable condition. Also, before it is applied, the paint material must be completely mixed or it will not achieve its maximal protective function.

3). Ambient Condition

The ambient condition should comply with the specification to allow the paint materials to cure well and adhere strongly to the steel surface. Moisture on a blasted bare steel surface will reduce the binding strength and cause premature failure of the painting. Also, when the air temperature or humidity is too high or too low, defective painting, such as blistering, pin-holing, and cracking can occur. For example, no paint should be applied when the steel surface temperature is less than 5°F above the dew point. In addition applying paint in a high wind environment will result in excessive drift, over-spray, dry spray, and uneven coating.

4). Painters' Skill

Skillful painters are essential in obtaining well painted products. The width of one path, the angle at which the inspectors hold the spry guns, and the distance between the spray gun and the steel surface are all key elements to the quality of final products.

5). Surface Cleanliness

If the surface is clean, the coating can have a stronger binding strength to the substrate, facilitating a longer service life. Contamination may include: 1) mill scale, 2) oil/grease, 3) rust, 4) chemical contaminants, and 5) loose coating. All of these must be removed from the existing surface to obtain adequate adhesion strength. Solvent cleaning, high pressure water washing, and abrasive blasting are used to clean steel surfaces. Blasting, which generates the profile, and remove the rust, mill scale, is the most common and efficient process used in surface preparation.

6). Profile

The roughness of the metal surface has a significant impact on the adhesion between paint and its substrate. If it is overly smooth, there is a deficient mechanical bond. If it is too rough, there is difficulty in obtaining an adequate coating thickness to cover entire irregular surfaces.

7). Thickness of Primer

One of the most common reasons for coating failure is inadequate paint thickness. The durability and performance of the painting product will be reduced if the film thickness is less than the recommended thickness. In contrast, over-thickness is also detrimental, causing such problems as mudcracking, skinning, sagging, etc.

8). Thickness of Top Coat

The top coat is applied to protect the primer from environmental attacks. A certain thickness of the top coat is necessary to provide a shield function.

9). Cleanliness Between Coats

Before applying paint on the existing coating, dirt, oil, and debris must be removed. A new coating will not adhere strongly to the existing coat if the surface of the existing coat is unclean.

10). Defects Detectable by Visual Inspection

Many of the flaws cannot be determined by measuring the film thickness. Visual inspection is necessary to detect such serious defects as pinhole, bubbling, dry spray, and sage.

Among the above ten quality parameters, paint material should be checked in either the field or the INDOT's laboratories. The operators' skill should be supervised with formal or informal contractor pre-certification programs. Other parameters, such as dry spray and bubbling, are qualitative parameters that should be checked by trained inspectors. Quantitative parameters such as coating thicknesses can be measured with specific equipment. A step-by-step guide to check these quality parameters in the format of inspection checklists will be presented in subsequent chapters.

2.3 Quality Assurance

Many DOTs are now using "recipe" types of specifications to control the quality of their bridge painting. The specifications indicate what materials should be used, how the surface should be prepared, and how the paints should be applied. In addition, inspections of material and work are made at various stages of painting and at the completion, before acceptance. With so many variables involved in the painting process, the resulting quality of the final painting product varies. Painting quality could be better assured by allowing the contractors to control more of their operations. DOT, on the other hand, could emphasize the end-result, and specify criteria for accepting the work. That is, the contractor assumes more responsibility for quality process control and DOT assumes more responsibility for specifying the requirements, the acceptance criterion, and inspecting of the product. This QA system can better allocate the responsibility for quality between the contractor and the owner.

According to Obrien, "*QA is all planned and systematic actions necessary to provide adequate confidence that a structure, system or component will perform satisfactorily and conform with project requirements. Quality Control (QC) is the specific procedures involved in the Quality Assurance process*" (Obrien, 1989). In other words, QA is applied to ascertain the quality of construction necessary for an end-product to perform its intended function. It encompasses design, planning, inspection, sampling, testing, and many decision criteria. In its board definition, it relates to the

overall problem of obtaining the required quality. In its simple terms, QA addresses the following four questions (Maslin, R. William, Stephens, B. Louis and Arnoult, D. James, 1983):

1. What do we want?
2. How do we order it?
3. How do we make sure that we get what we order?
4. What do we do if we do not get what we ordered?

The answer to the first question includes the total highway planning and design. The planning determines the needs and establishes broad goals and actions to meet those needs. The design determines the quality levels to be achieved. All these combine to define the needs with respect to materials and properties of the highway components.

The answer to the second question depends on the translation of a design into plans and the specifications in which the required quality is clearly spelled out.

The answer to the third question is to rely on 9 reliable inspection, sampling, and testing procedure. The skill and integrity of the inspector are essential to make sure that DOTs get what they order.

The answer to the 4th question is to install a reasonable and "fair-to-all" criteria to accept or reject the work. An adjustable pay schedule is another alternative that the DOTs can choose (Chang, Luh-Maan, 1989).

Nevertheless, current INDOT specification does not specify the requirements of 1) where to take measurements; 2) how many

measurements are needed to make acceptance decisions; and 3) what quality level is acceptable. The interviews with highway inspection personnel revealed that the inspection process is now substantially based on personal judgements. To solve the problem, the statistical sampling method can be a powerful tool. The statistical sampling is the core of the QA specification, which can be utilized to establish a risk-controlled inspection process. Its other advantage is that it supplies an approach to the adjustable pay schedule.

Adjustable Pay Schedule

Another benefit of QA specification is the adjustable pay schedule. Most specifications draw a sharp line between acceptance or rejection, and do not properly consider normal variability of materials and construction (Quality ..., 1979). If the quality of the product is less than specified, it may be advantageous to leave it in place and reduce the amount paid. The strategy of receiving a changeable payment related to the out-coming quality is known as an adjustable pay schedule. This concept is totally new to painting construction. Here's how it works: if the obtained thickness of the painting film does not meet the specified requirements, the contractor will be asked to either add more paint on the existing coating or remove the finished paint. However, if more paint is added on the existing film, the binding strength between the existing and new paints is questionable. The additional effort may not extend the service life of the product as expected. Even when the remeasurements show the increase in the film thickness, this

does not mean that the quality is improved accordingly. On the other hand, the owner may insist that the nonconforming painted products be removed and repainted. It is a tremendous waste if the nonconforming painted product still has a significant period of service life. However, under the current inflexible system there is an option to solve the previous two problems, an adjustable pay schedule can be implemented.

2.4 Comparison with other QA Programs

The QA system based on statistics-oriented specifications is being developed and adopted by many state highway agencies throughout the nation. For example, quality characteristics, sampling schemes, acceptance plans, and adjustable pay schedules have been applied in the specification of highway concrete pavement construction (James L, Burati, Jr., and Charles S. Hughes, 1990; Weed, M. Richard, 1989; Willenbrock, H. Jack and Kopac A. Peter, 1977).

Although some may argue to the contrary, QA programs do not raise the bid price. However, a 1975 survey shows that the QA program did not increase the costs in highway construction. The American Association of State Highway and Transportation Officials (AASHTO) Committee conducted this survey in relation to QA specifications and the application of those specifications. Twenty-five States that had used QA-type specifications responded to the question, "Have bid prices been affected by QA specifications and to what degree?" The answers are significant since only two out of

twenty-five states responded that "higher or unbalanced bids" resulted from the use of QA specification (Wheeler, B. 1980).

Many concepts of quality assurance (QA) systems in pavement could be applied in painting construction. But, there are several barriers in transferring the QA system between these two types of construction areas. The particular features of painting construction which cause the barriers are summarized as follows.

Complex Sample Lot Scheme

Currently, the QA program in pavement stratifies the concrete or bituminous pavement to several equal-sized lots in the whole project. Then, a specific number of lots are randomly selected from all available lots. Within the selected lots, a pre-defined number of measurements are randomly taken. From the results of these measurements, the quality of the pavement is decided. Later on, an adjusted pay schedule based on the measured quality is applied.

For steel bridge painting construction, however, the configurations of bridge structures are much more complicated than those in the pavements. For pavement, the sampling lot scheme only involves characteristics in terms of width, length and thickness. However, for bridge painting, even within one beam member, there are several structure member components such as flanges, webs, stiffeners, etc. Furthermore, the applicabilities differ from area to area within one bridge. This causes a variation of quality and should be accommodated in the sampling scheme plan.

Inexpensive Measuring Cost

The costs associated with one sample in pavement construction are much higher than those in painting construction. For pavement, quality characteristics such as compressive strengths, thicknesses, and densities are required to define the quality. Usually, samples are taken to the laboratory, which may be several mils away from the construction site. The cost associated with one pavement sample is quite significant.

For painting construction, quality parameters such as surface cleanliness, anchor profiles, thicknesses of primers, and thicknesses of finish coats can be measured in a few seconds. The direct cost associated with one measurement is comparatively trivial.

High Accessing Cost for Taking Sample

The cost for "accessing" the project to take samples in painting construction is higher than that in pavement construction. The pavement inspectors can directly access the pavement without difficulty. They can easily take cores from the pavement by the random sampling method. On the other hand, steel bridges may cross a river or may be an over-path of a heavy duty highway. If the inspectors want to check the painting quality of the steel bridge, they may first need to block traffic, and then arrange equipment that will allow them to approach different spots of the structures. Especially when a bridge spans a river, it is very difficult and dangerous to access the structure under bridge decks where

corrosion is apt to occur.

"Specific problems require specific solutions (Crosby, 1979)." For the above reasons, painting construction requires its own procedures to run the QA program. A specially-designed specification is required to meet its needs.

Chapter 3

Research Methodology

3.1 Introduction

To develop an unbiased quality assurance specification for highway steel bridge painting construction, research should be conducted from the standpoint of both highway agencies and contractors. Many efforts are necessary to obtain a rational and feasible solution for the deficient quality in current painting construction. The research methodology can be divided into three phases. There are: 1) Problem Realization phase, 2) System Development phase, and 3) Finalization phase. Figure 3-1 shows a schematic presentations of the research.

The problem realization phase, includes four tasks: conducting a literature review; interviewing the expert in shops, fields and administration offices; attending painting construction conferences; and collecting existing painting quality data. After completing these four tasks, the primary knowledge to solve the research problems was available. This knowledge consists of: 1) the decision of quality parameters, 2) the problems of current painting construction, and 3) the present existing quality level. After these three types of information were obtained, the system development phase of an acceptance plan began.

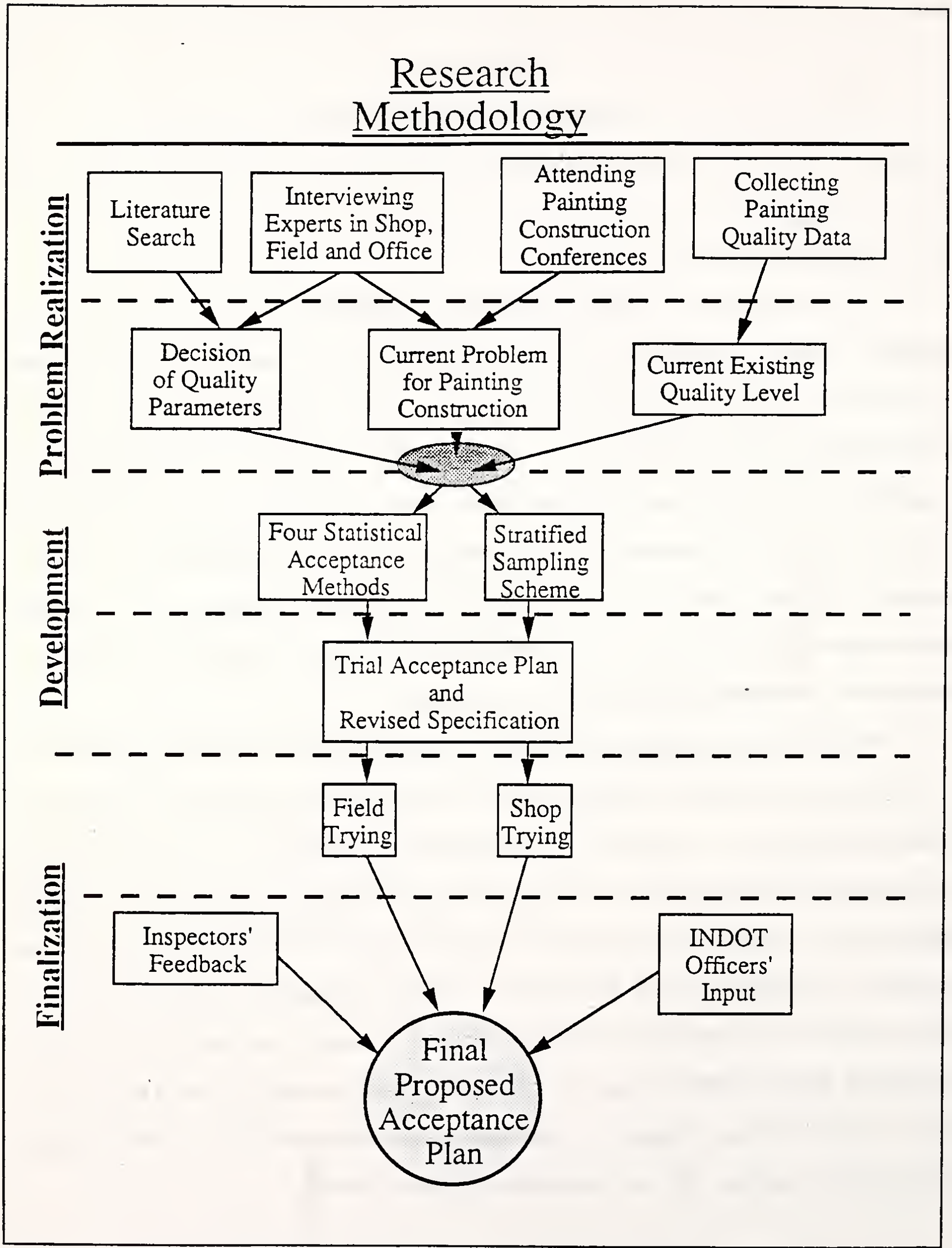


Figure 3-1: Flow Chart of Research Methodology

In the development phase, the stratified sampling scheme and statistical acceptance methods were linked to form a trial acceptance plan. This plan will be tried in both shops and fields in the next phase. In addition, current INDOT specifications for painting construction were revised, based the interviews, other states' specifications, and the experiment reports from Steel Structure Painting Council (SSPC) and the federal highway agency. This revised specification can help INDOT to significantly improve and rewrite the existing specification.

The finalization phase is the most important stage to make the acceptance plan reasonable and feasible. In this phase the trial acceptance plan was introduced to both the shop and field. The inspectors were asked to follow the trial acceptance plan. The work load imposed on the inspectors and the accuracy of the sampling plan were both reconsidered. Feedback from the inspectors and the input from INDOT administration officers were calibrated into the final acceptance plan. The final proposed acceptance plan incorporates the statistical sampling method, a clearly defined stratified sampling scheme, and a systematic decision-making process.

3.2 Three Research Phases

The details for the three phases illustrated in Figure 3-1 are described in detail in the subsequent sections.

3.2.1 Problem Realization Phase

To gain knowledge about current inspection practice, four tasks were outlined: 1) literature review; 2) interviewing the expert in shops, fields and offices; 3) attending painting construction conferences; and 4) collecting existing painting quality data. To grasp the complexity of painting construction, several conferences were attended and many painting experts were interviewed. To determine the painting quality parameters, literature was reviewed and painting specialists were consulted. To be aware of the quality of current painting project, data were collected from both shops and fields.

Quality Parameter Search

Many reasons for the premature failure of painting products include poorly written specifications, the choice of a wrong paint material for a given environment, or a service environment that is more severe than originally anticipated. However, it is estimated that approximately 75% to 80% of the premature failure of all painting products is caused, in whole or in part, by deficient surface preparation and/or coating application (SSPC, 1989, p 183). The purpose of the acceptance plan is to assure quality by requiring that the outcome products meet certain specifications. The first step in developing a statistical specification is to decide what parameters should be used in the acceptance sampling plan. Two tasks to uncover the quality parameters are: 1) reviewing the literature, and 2) interviewing highway personnel,

fabricator shops personnel and painting construction contractors.

Literature Review

During literature review, state-of-art quality control and sampling methods were evaluated. Many documents from Transportation Research Board (TRB) involving the painting were reviewed. the SSPC manual and video tapes were studied to obtain a comprehensive knowledge of painting construction. Several books and journals in quality and painting industry were studied.

In addition, the specifications from the states of Indiana, Ohio, Kentucky, Illinois, Michigan, Pennsylvania, Virginia and the Steel Structure Painting Council (SSPC) were reviewed. Their requirements are compiled, tabulated and shown in Appendix 3-1. The comparison provides a potential of learning from others' experience. For instance, the review of the specifications of other agencies shows that the INDOT does not now require upper limits of primer and there is presently no requirement for the anchor profile. Also, the INDOT's requirement for the surface cleanliness is SSPC-SP6; other states require SSPC-SP10.

Interviews with Experts

Twenty interviews were conducted with specialists in both shop and field. These specialists includes the contractors, painters, DOT personnel and the experts from painting consulting firms. During the interviews, many problems of painting construction were uncovered and knowledge about painting techniques were gained.

Videotapes and photographs were taken during the interviews for future retrieval.

Attending Painting Construction Conferences

To keep informed about current problems for painting construction, several conferences were attended by the researches. These conferences included: 1) inspector training short course; 2) contractor certification conference (Illinois); and 3) paint material supplier/contractor meeting.

The inspector training short course was held by INDOT in spring of 1990 in Indianapolis, Indiana. This four-day course, given by S.G. Pinney & Associates Inc. gave the researchers background and knowledge for painting quality inspection.

The contractor certification conference, held by IDOT in Springfield, Illinois, in March 1990, was an educational conference. During the conference, an initial structure of the program was proposed. Then, the potential problems for the implementation of the contractor certification program were discussed.

Another conference in the Chicago area was sponsored by the paint supplier. Appropriate treatments for paint material and its application were presented to contractors and inspectors at the conference. The interactions between contractors, inspectors, and paint suppliers were aimed at eliminating the painting problem in the field.

Collecting Existing Painting Quality Data

For this task, data were collected by visiting 6 bridge fabricators' shops and 13 bridge sites. To keep the data confidential, the names of the fabricators' real names, rather than shops and bridge sites are designated by a series of numbers for the remainder of this report. The data collected from the shops all belong to the on-going projects. For field painting data, most of the 13 bridge sites were on-going projects, and some of them were recently-finished projects which were done less than one year before measurements. In total, 228 measurements were taken from 6 fabricator' shops. For primer, 8,535 measurements were taken from both shop and field. For top-coat, 10,480 measurements were taken from the field. The details about data collection and analysis are explained in the successive chapters.

3.2.2 Development Phase

After the problem realization phase, where information about the quality parameters was studied, the current problems of painting construction and the existing quality levels were addressed. Meanwhile, various quality control and sampling methods in construction and other industries were evaluated. Accordingly, four acceptance sampling methods were developed. They are: 1) Variable Single Sampling; 2) Attribute Double Sampling; 3) Variable Single Sampling without Risk Control; and 4) Attribute Proportion Single Sampling. Among these four sampling methods, Variable Single Sampling method was initially adopted and tried in

the field. By combining the sampling method and a stratified random sampling scheme, a set of checklists was designed. In the stratified random sampling scheme, with random numbers, inspectors were guided to take a certain number of measurements on specific areas. Once the results of the measurements are applied to the formula of Variable Single Sampling, acceptance or rejection decisions can be made. Additionally, because of SSPC and the other agencies' experience, the painting specification of Indiana 88 is revised.

3.2.3 Finalization Phase

The initial acceptance plan was first tried in shop painting construction. However, the inspectors responded that the trial acceptance plan was infeasible because it require a strong statistical background. The same response was found from field inspectors. As a result, a series of modifications with different sampling methods were undertaken to increase the feasibility of the acceptance plan. Feedbacks from contractors and inspectors were analyzed to revise the inspection procedure. The input from INDOT administration office was also adopted. Finally, a comparatively implementable acceptance plan was established.

Chapter 4

Findings of the Interviews

4.1 Background

During the problem realization phase of this research, twenty visits were made to interview specialists. These specialists include the DOT personal, contractors, painters, and the experts from painting consulting firms. As a result of the interviews, a more comprehensive understanding of current bridge painting practices and the degree of existing quality was achieved. Meanwhile, a set of questions was devised and presented to the INDOT inspectors (Smitt, Bob, 1990).

4.2 Problems Found and Discussion

The findings from the interviews are discussed as bellow:

1. Inconsistent Acceptance Procedures and Decision Criteria

The interviews revealed that coating thicknesses were checked on the areas according to inspectors' individual preferences. The criteria for making an acceptance decision varied among the inspectors. Using the measurement of film thicknesses as an example, some inspectors judged the quality based on the average of the film thickness; but some inspectors used the proportion of the measurements, which is out of the limit of 2.5 mils; some

inspectors do not even measure the film thickness. Current specification does not give guidance about: 1) where to take measurements; 2) how many measurements are necessary; 3) how to make an acceptance/rejection decision. As a result, each inspector had his/her own acceptance procedure and strategy.

2. Shortage of Gauges

In the field, temperature, moisture and wind speed are considered, but not measured by any devices. It is generally a "judgement call" and common sense is used. Also, there is a shortage of dry film thickness (DFT) gauges. Quite often, the inspectors in a whole district share one gauge. Greater access to the gauges is needed.

3. Untrained Inspectors

In one instance, an untrained, inexperienced inspector hired just for the summer was in charge of determining quality of the painting. None of the inspectors interviewed checked the humidity and dew point prior to priming or top coating. Several inspectors did not realize that a gauge to measure the humidity and dew point existed. Many of them relied upon the "natural feel" of the air temperature to determine if the conditions were acceptable to apply primer or top coat. The general attitude of "it looks good" applied to a large number of inspectors. Further knowledge was needed for many inspectors. The lack of statistical background was common to them. When the statistical acceptance plan was introduced, the plan

was rated infeasible due to the necessity of the statistic computation.

4. High Reliance on Visual Inspection

Most of the current inspectors relied heavily on visual examination. Several defects, such as dry sprays and runs, depend largely on human judgement. The contractors are required to repaint areas that deteriorate before a preset time. Because visual inspection is still necessary, several quality parameters rely on human judgement, which is apt to be subjective. Also, several parameters, such as mixture of the paint material, should be examined during the process stage of painting.

5. Poor Awareness of Current Quality Problems

Most of the inspectors agreed that adequate quality was being achieved. However, after many inspectors became aware of problems that were observed by the researcher, they realized that there was a margin for improvements to the current specifications.

6. Undefined Responsibility between Shops and Fields

During the handling of primed beams, quite often, the primer is worn off by abrasion against paint stands and crane hoists. No assurance of quality is maintained during transportation and handling, except by the contractor's word. Another problem occurred when primed beams remain in the fabrication shop yard for an extended period. In one case, where the beams were not painted on

the top flange, so rusting occurred in the shop yard. The beams were stored outdoors in the shop yard and orange discoloration resulted on the side of the web and lower flange from rust stains dripping or running down from the rusting areas on the top flange. The contractor claimed that the discoloration should be removed using surface blasting with an abrasive and wanted additional monetary compensation. INDOT refused to pay the money and claimed that the dispute should be resolved between the prime contractor and the fabrication shop. The beams had remained in the shop yard for nine months at the time of interview.

7. Deficient Supports for Assessing the Painted Bridge in Fields

In fields, film thickness measurement is generally taken on easily reached areas. The areas are commonly near the abutments since they can be reached by standing on the side slope at both ends of the bridge. In many cases, the middle span areas are not checked by inspectors. One reason is that inspectors do not have the appropriate equipment, such as pick-up trucks, to access the bridges. Another reason was that the inspectors had no motivation to go the extra effort of testing the middle areas; therefore, these areas were largely ignored.

8. Lower Priority Compared with Fabrication in Shops

One inspector would not inspect the painting of the bridges on the project claiming there was "no time to do so." That inspector stated that he/she, "would trust that the contractor would do a

good job." In another case, there was "too much happening on the project" for the project engineer to perform any inspection. That engineer considered the painting inspection the lowest priority on his list and had no gauge to check the paint thickness.

9. Inadequate Formal Documents

Documentation varied among inspectors. Usually inspectors need to design their own inspection forms. No consistent forms were required among inspectors. Because there is no formal form or document to record the data, legal problems can arise if the products are rejected. Inspectors would have more feeling of security if a standard documentation form were available to them.

10. Questionable Make-Up Process

Additional coats on the existing coat are usually requested when inadequate coat thickness is found by inspectors. However, the binding strength between existing and new paint is doubtful. The service life of the product may not improve according to the increase of the film thickness. In this case, the contractors may not pay attention to whether they can pass the "first" inspection. To them, the unqualified coating can always be repaired by putting on an additional coat. Therefore, the quality is difficult to maintain.

Chapter 5

Data Collection

5.1 Introduction

Specifying a rational quality level in acceptance plans is important. However, it is often difficult to determine whether or not the designated quality requirement in the specification is realistic. Research revealed that *"arbitrary acceptance decisions by the highway's representatives were frequently made. These increased the cost because the contractor has been burned before and thus has allowed contingency for such capriciousness"* (Abdum-Nur, A. Edward, 1981). Thus, a realistic specification for quality assurance systems will be beneficial to both agencies and contractors. An effective approach to solving these problems is to examine the distribution of current quality characteristics. Once the real world properties are recognized, the sampling plan and acceptance criteria can be set up correspondingly. Another advantage in examining the quality of the current project is to expose the trend of quality on particular areas in one project. For example, the data may reveal that the quality on certain areas is apt to be deficient due to its applicability. Being awareness of the tendency, allows the specification to be designed to take care of that particular area. Also, the inspectors can be trained to detect the quality on areas that are prone to be defective.

To collect data, measurements were taken by visiting 6 bridge fabrication shops and 13 bridge sites. For the remainder of this report, fabricators' names, bridge sites or states' names will be designated only by a series of numbers, instead of real names. The data collected from the shops all belong to on-going projects. For field painting data, most of the bridge sites were on-going projects, and some of them were recently-finished projects that were completely less than one year before measurement. Totally, for profile, 228 measurements were taken from 6 fabricators' shops. For primer, 8,535 measurements were taken from both shops and fields. For top-coat, 10,480 measurements were taken from fields. The details about data collection and analysis are explained in the successive chapters.

5.2 Instruments Used

Instruments used in each stage for data collection are described below:

Surface Cleanliness Measurements

The standard, "SSPC SURFACE PREPARATION SPECIFICATION VIS- I," was used to inspect the surface cleanliness of bridges. The grades of cleanliness can be SSPC-SP10, SSPC-SP6, and so forth.

Profile Measurements

Surface profiles were checked by "replica tape." The Testex Press-O-Film Replica Tape has an emulsion film of microscopic

bubbles attached at a uniform, 2.0 mils of thick mylar. When applied, the tape is pressed onto the blast-cleaned surface, emulsion film side down, and the mylar is rubbed vigorously with a blunt instrument. The peaks of the profile will break the bubbles and ultimately touch the thickness of mylar. The tape is then removed and measured using a spring loaded micrometer, which provides a reading from the upper or outermost surface of the mylar to the high spots on the emulsion that are not totally crushed (corresponding with the valleys of the profile). The total micrometer reading is adjusted for the thickness of the mylar by subtracting 2.0 mils from the results to provide a direct reading of the maximum average profile (SSPC, 1989 p.193). The replicas of the profile can be kept on file permanently for future reference.

Dry Film Thickness (DFT) Measurements

A dry film thickness (DFT) test instrument, Minitest Model 4000, is used to collect data for primer and top coats. This gauge utilizes the principle of magnetic-induction and has an accuracy of 4% or +/- 0.04 mils. The required minimum base thickness is 20 mils. The accuracy of the digital model has an accuracy of 4%, which is better than the traditional banana gauge.

One of the features of this gauge is its memory capability. It can store 3,000 readings in its memory. By using this gauge, the researchers do not have to write down the readings on data sheets. The stored data can be transferred to a personal computer (PC) with a cable. With this function, a lot of time can be saved in typing

in the data, and human errors in recording data can be more easily avoided. It has proven to be very efficient. After being reformatted, the data were transferred from a PC to Purdue University Computing Center (PUCC) mainframe. Then these are analyzed with a statistical software called "SAS." The advantages and disadvantages of this type of instrument are:

(A) Advantages:

Minitest 4000 is a Non-Destructive instrument with installed memory and statistics computing capabilities. The gauge can store up to 3,000 measurements which can be imported into the PC. The gauge has a probe connected to a cable that allows the user to access broad areas. Inspectors may need to check the DFT on areas such as the inner part of a box beam or the connection corner of webs and flanges. These areas are almost impossible to be measured by the traditional equipment like banana gauge. However, by using the cable-connected probe, inspectors can access the above special areas.

(B) Disadvantages:

Compared with other traditional gauges, Minitest 4000 is expensive. The operation to store measurements and import the data to PCs is complicated. For multi-coat systems, compared with the destructive type of gages such as Tuck Gauge, this magnetic DFT gauge cannot separate the thicknesses for different layers of coats.

Verification by Comparing with INDOT's Gauge

To obtain a confidence of accuracy, the Minitest 4000 was investigated by comparing it to other DFT gauge. The INDOT recently purchased a batch of elcometer DFT gauges for its inspectors. To compare these two types of gauges, measurements were taken in the same small spot. The data collected with these two types of gauges are listed in Table 5-1. It shows that the readings taken with these two types of gauges were highly compatible. The difference of their means is as little as:

$$2.15 \text{ mils} - 2.14 \text{ mils} = 0.01 \text{ mils}$$

5.3 Error Sources

Some error sources that potentially influence the accuracy of the data are summarized below:

(1) The data were collected by two persons. When different operators measure the same products, the results may differ. The variation due to the difference of the two operators was integrated into the measurements.

(2) The error of the Minitest DFT gauge specified in the technical report is 4% or ± 0.04 mils.

(3) Dust on the surface of steel bridges where paint thicknesses were going to be measured was removed with a brush. However, cleanliness of the surface was not assured. If the surface is

not clean, the thickness of the dust will be integrated into the measurement.

(4) For field painting measurement, gauge calibration was taken in a pre-prepared metal plate. A calibration factor was then used to adjust the data. This procedure is different from the SSPC Type-II calibration method.

*) Test was done on the painted surface with 1.0 sq-cm size. *) Calibration is taken on the identical metal plate. *) Unit : mil (1/1000 inch)			
Measure No.	Minitest 4000	Elcometer 246	Remark
1	2.19	2.3	
2	2.08	2.18	
3	1.97	2.45	
4	1.85	2.08	
5	2.14	2.11	
6	1.95	2.23	
7	2.11	2.16	
8	2.33	2.14	
9	1.86	2.14	
10	2.08	2.08	
11	2.26	2.16	
12	1.97	2.14	
13	2.23	2.13	
14	2.34	2.21	
15	2.27	1.98	
16	2.17	1.99	
17	2.18	2.11	
18	2.06	2.21	
19	2.09	2.04	
20	2.14	2.16	
21	2.1	2.01	
22	2.25	2.02	
23	2.43	2.21	
24	2.1	2.18	
25	2.26	2.11	
26	2.21	2.18	
27	2.33	2.09	
28	2.22	2.14	
29	2.26	2.13	
30	2.15	2.14	
Mean=	2.152666	2.140333	
STD=	0.137208	0.091741	
N=	30	30	
Max=	2.43	2.45	
Min=	1.85	1.98	

Table 5-1: Measurements From Minitest 4000 (Research) vs. Elcometer 246 (INDOT)

5.4 Progress of Data Collection

5.4.1 Sampling Philosophy

As mentioned before, the cost of accessing a steel bridge to inspect bridge painting quality is significant. As a result, when the researchers gained an opportunity to access a bridge, abundant data were taken. The amount of the data was obviously more than necessary to determine the quality of a painted bridge. The reason for doing so was that those data can be utilized to simulate a sampling process and to verify if the designed statistical specification is proper. Also, a pilot study was conducted as a first step in the data collection task.

5.4.2 Pilot Study

A pilot study was conducted on the U.S. Highway 36 truss bridge over the Wabash River at Montezuma, Indiana, on June 1 and 5, 1990. The bridge was of a truss-type configuration and received maintenance paint during the summer of 1989. The following description provides a picture of the inspection practices.

The day began by meeting with an INDOT traffic control crew from the Veedersburg Subdistrict (Crawfordsville District) and an INDOT man-lifter machine crew from Crawfordsville. They were present at the east end of the bridge when our research team arrived at 9:00 a.m. Having established a methodology to measure the bridge the day before, we explained to the crews how the paint thickness measurement would be performed.

The collected measurements of the truss bridge were divided into two components, truss members and connections, to provide a methodical way of obtaining data. Different members were numbered so that the data could be easily understood after collection. Measurements were recorded by an electronic paint thickness gauge and by manual collection on data sheets. The data sheets provided an assurance of collection, while electronic collection with the thickness gauge was not assured. The operator was shown where to position the man-lifter bucket. Difficulty was encountered during measurement when several members and connections were difficult to reach; therefore, the data were somewhat biased to easily reached areas. Floor beams, lower chords, and stringers underneath the bridge deck were difficult to measure. Since those members were approximately 20 feet above the Wabash River and the accompanying shoreline, a majority of the measurements were made within an arms-reach of the bridge abutment. The measurement of one side of a span required 1 and 1/2 hours. Because of long travel distance (1 and 1/2 hours one-way) and lunch (1 hour), measurements were restricted to two spans on the south side of the bridge.

The weather on June 1 was sunny with a temperature around 80 degrees, a humidity of 90 percent, and a strong wind from the south at 25 m.p.h. Except for the strong winds, it was an ideal day to take accuract measurements. The weather on June 5th, the second working day, was much colder with a temperature of 60 degrees, a humidity of 40 percent, and a wind from the northwest at 20 m.p.h.

Visual inspections of the truss members and connections were recorded. These observations provided a qualitative assessment of the actual condition of the painting work that the thickness measurements could not provide. The research team had the opportunity to touch the surface of the paint to develop a feel for the texture. Over-spray, rust, and areas that received no paint were observed. Also, photographs of the bridge were taken.

After the pilot study was conducted, experience was gained in data collection. Classification of "complete" bridge painting and "spot" bridge painting was needed. Designations of Type I and Type II bridge painting were applied to each method, respectively. Several visits were made to Type II bridges receiving maintenance painting. Difficulty in assessing a Type II bridge was encountered because there was no way to know when taking thickness measurements whether the mil thickness reading was recently applied maintenance paint or the original topcoat. This predicament turned the attention away from spot bridge painting project analysis (Type II) and focus was concentrated on complete bridge painting (Type I).

5.4.3 Procedure for Major Data Collection

A systematic process was developed for collecting data after the pilot study. The detailed data analysis is presented in the following chapter. Each of the three basic steps involved in painting. (surface blasting, priming, and top coating) was examined separately so that an appropriate data collection strategy could be designed. The sampling procedure was established so as to

provide an accurate statistical representation of the data. After the pilot study, the painted bridges visited were all simple-span bridges with I-beam configurations. Lateral bracing configuration varied with each project, ranging from L-beams to I-beams.

In fabricators' shops, the data collection for an I-beam section was divided into five components: 1) bottom of top flange, 2) web, 3) top of bottom flange, 4) edge of bottom flange, and 5) bottom of bottom flange. Data collection for a lateral bracing section was treated as one component and not divided into sections. A minimum of 30 measurements was taken on each section of the beam.

Blasted Surface

Two surface blasting methods are currently performed on fabricated beams: 1) wheel braider, and 2) sand blasting. The wheel braider method uses an enclosed chamber to mechanically force steel shot at the surface of the beam. The sand blasting method uses compressed air to force a vehicle abrasives at the surface of the beam. Several kinds of vehicle abrasive were encountered at the fabrication shops including silica sand, Mississippi River coarse sand and black beauty (a coal-derived, sand-like particle).

Profile tape and a profile gauge were used to determine the peak-valley distance inflicted by the surface blast vehicle. Measurement of the blasted surface profile treated the beam as one unit without breaking it into components.

Primed and Top Coated Beams

All primed and top coated beams were measured with the Minitest 4000 dry film thickness gauge. Measurements of primed beams were randomly taken over the distance of the beam. Measurements of erected beams that had received primer and topcoat were measured perpendicular to the axis of the beam. This cross-sectional method was applied at the ends and centers of the beams. Measurements near connections and on the surface of the outer beams were avoided due to heavy applications of topcoat. Lateral bracing was not divided into components, but treated as one unit.

Chapter 6

Data Analysis

6.1 Introduction

The required quality levels play an essential role in the QA specification. But how can the highway agency decide on the required quality level in their specification? How can the acceptance plan be conducted? And how can we assure that the specification is reasonable? A practical approach to solving these problems is to investigate the distribution of existing quality characteristics (Wadsworth, M. Harrison, Stephens, Kenneth S. A. and Godfrey, Blanton, 1986). After the real world underlying properties are clear and realized, then the sampling plan and acceptance criteria can be developed. Another benefit in analyzing the quality of current projects is the awareness in tendencies insufficient quality on specific areas. This trend can be appraised and avoided with an efficient acceptance plan.

Painting construction involves three basic steps including: 1) surface blasting, 2) priming, and 3) top coating. These three steps were examined separately in the research. In the rest of this chapter, the data of profile, the dry film thickness (DFT) of the primer the and total topcoat are analyzed.

An error source regarding random sampling was induced during the data collection stage. For non-biased information, the samples

for data collection should be chosen randomly. That is, ideally, the bridge sites, and fabricators' shops should be randomly selected for the data collection. However, the accessibility varied among different shops and bridges. This made random selection in data collection impossible. For example, several bridges were initially selected for data collection, but help for accessing these bridges from the district highway agency was unavailable. Consequently, the researchers avoided these bridges. Likewise, some of the chosen fabricators did not enthusiastically allow the researchers to access their shops. Therefore, instead of random selection, fabricators' shops or bridge sites were chosen in part by the availability of help. This limitation creates a certain degree of error in terms of random sampling.

The data were collected by visiting 6 bridge fabrication shops and 13 bridge sites. In the rest of the report, fabricators' names, bridge sites and states' names will be designated only by a series of numbers. All data collected from the shops belong to on-going projects. For filed painting data, most of the bridges were on-going projects, and some of them were recently-finished projects which were done less than one year before measurement. For profile, 228 measurements were taken from 6 fabrication shops. For primer, 8,535 measurements were taken from both shops or fields. For top-coat, 10,480 measurements were all taken from fields. A summary table for profiles, primers and top coats is shown in Table 6-1. This table includes parameters such as: sample size, mean value, standard deviation and percent out of limit. Also, more detailed

data are shown in Appendix 6-1.

Determinant	Mean	STD	N	Max	Min	Spec.	%Out
Profile	2.47	0.29	228	4.20	1.70	1.5-3.5	1.40%
Primer	3.16	1.20	8535	11.70	0.08	>=2.5	38.28%
Top-Coat	6.65	2.53	10480	46.80	0.60	>=5.5	37.56%

Table 6-1: Summary table for data collected in the state of Indiana

To explore the existing qualities, an efficient method, the experimental design, was applied by using the statistical computer software called "SAS." In addition the normality test named "W-test" was done with the help of this computer software.

6.2 Categorization of the Data

There are many parameters defining the quality of painting construction. The three parameters covered in the data analysis are: 1) Profile, 2) Primer Thickness, 3) Topcoat Thickness. Detailed analyses are presented in the following sections.

6.2.1 Profile

Currently, INDOT does not specify the profile peak-valley distance for steel surface preparation. In this study, the requirement (1.5 - 3.5 mils) for profile suggested by SSPC is used

as a criterion to determine conformance of the product. Based on this criterion, percent of defective for profile was computed. The profile data collected from 6 fabrication shops are summarized in Table 6-2.

Location	Mean	STD	N	SSPC-req	% out	Abrasive
Shop #1	2.08	0.22	22	1.5-3.5	0.0%	Silica Sand
Shop #2	2.54	0.35	47	1.5-3.5	0.0%	Black Beauty
Shop #3	1.93	0.25	20	1.5-3.5	0.0%	Silica Sand
Shop #4	2.65	0.30	53	1.5-3.5	0.0%	River Sand
Shop #5	2.60	0.35	49	1.5-3.5	8.2%	River Sand
Shop #6	2.45	0.19	47	1.5-3.5	0.0%	Black Beauty
Total	2.47	0.29	228	1.5-3.5	1.4%	

Table 6-2: Table for Profile in Fabrication Shops

The table shows that nearly all measurements were within the SSPC requirement of 1.5 to 3.5 mils. The only exception was Shop #5 where 8.2% of the measurements were beyond the limits. This deviation correlates to the type of abrasive vehicle used. The table indicates that Shop #5 uses a river sand, which has a larger particle size than other abrasives. This probably created a greater peak-valley distance during surface blasting. Shop #4 also uses

river sand abrasive; however, all measurements were within the SSPC requirement. The mean of both fabrication shops is almost identical, but the standard deviation of Shop #5 is larger (0.35 mil), accounting for the 8.2% out of bounds. To sum up, the profile in the steel surface preparation for current painting construction is mostly implying the requirement.

6.2.2 Primer

The INDOT specification now requires a primer thickness of no less than 2.5 mils, and no upper boundary on primer thickness is specified. Based on this criterion, Table 6-1 shows that 38.28% of all primer thickness measurements were less than 2.5 mils. This percentage indicates that the current INDOT quality assurance system is extremely deficient. A shortage of thickness gauges, training among INDOT inspectors, and/or a number of other factors indicates that beams that are not receiving adequate coverage of primer.

The percentage of measurements below 2.5 mils varied among fabrication shops. The results of three visits to Shop #1 had 85.9%, 14.2%, and 84.8% of the primer measurements below 2.5 mils. Shop #5 obtained a value of 36.0%; Shop #2, Shop #4, and Shop #6 achieved values of 4.6%, 2.6%, and 3.1%, respectively. This obvious variation in percentages below 2.5 mils indicates inconsistent quality assurance programs and different acceptance requirements among the various steel fabricator inspectors.

Primer Film thickness for Different States

During the data collection stage, 6 fabrication shops were visited. Most of the shops fabricate the structures of steel bridges not only for Indiana but also for other states. Thus, the researchers obtained a chance to access steel bridges for several states. Besides Indiana, the primer film thicknesses were measured on 6 states' new bridge projects. The data obtained are summarized in Table 6-3.

State	Mean	STD	N	require	% out	Limit of Error
State #1	3.27	1.19	8832	2.5	38.3%	1.0%
State #2	4.60	1.30	528	2.5	4.2%	1.7%
State #3	3.05	0.97	439	2.5-5.0	33.5%	4.4%
State #4	4.87	1.56	406	3.0-10.0	9.4%	5.1%
State #5	3.76	0.91	281	2.5	7.1%	3.1%
State #6	3.40	0.96	236	2.5	20.3%	5.1%
State #7	4.15	1.50	264	2.5	10.2%	3.5%

Table 6-3: Primer Film Thickness for Different States

The formula used to calculate the Limit of Error is:

$$h = Z(1 - \alpha/2) * (p * (1 - p)/n)^{1/2}$$, where

z() is the value obtained from the normal distribution table,

p is the estimated percent of defective, and

n is the sample size.

Based on a 95% confidence interval, let $(1 - \alpha)$ equal to the confidence interval, 95%. Thus,

===> $(1- \alpha) = 95\%$

===> $\alpha = 5\%$

===> $\alpha/2 = 2.5\%$

===> $Z(1 - \alpha/2) = Z(0.975) = 1.96$

Table 6-3 shows that State #1 has highest percent of defective coatings at 38.2%. State # 3 is ranked second in percent of defect at 33.5%. The State #2 has the best quality of only 1.7% out of limit. Because the data for a couple of the states were collected from only one shop, the data cannot stand for the whole existing painting quality for those particular states. However, it does show the general tendency of deficiency quality for several states' steel bridge painting construction.

6.2.3 Topcoat

Current INDOT specification requires that the film thickness combining the primer and top coat should be no less than 5.5 mils. The percentage of topcoat measurements below 5.5 mils varied among bridge sites. The data in Table 6-4 shows the comparison of statistics among bridge sites. Among all of the bridge sites, Bridge #7 had the lowest percentage of defect at 12.6%. The standard deviation was consistently between 2 and 3 mils, with the exception of 1.80 mils for Bridge #1. The mean value for Bridge #1

was less than the required 5.5 mils, obtaining a value of 5.09 mils.

Location	Mean	STD	N	INDOT-req	% out
Bridge #1	5.09	1.80	2639	5.50	62.6%
Bridge #2	6.50	2.67	2398	5.50	35.4%
Bridge #3	7.77	2.09	800	5.50	19.5%
Bridge #4	8.03	2.25	795	5.50	13.6%
Bridge #5	5.71	2.35	805	5.50	56.9%
Bridge #6	6.63	2.22	741	5.50	32.7%
Bridge #7	7.98	2.68	767	5.50	12.6%
Bridge #8	6.55	2.52	789	5.50	42.3%
Bridge #9	7.22	2.20	826	5.50	24.9%
Bridge #10	8.13	2.47	795	5.50	20.5%

Table 6-4: Top Coat Film Thickness for Different Bridges

6.3 Quality Variation within a Project

-- an Experimental Design Approach --

6.3.1 Motivation

When the researchers interviewed the inspectors on the job sites, it was found that many of the inspectors use their gauges to check film thicknesses only on the easy-accessing area where they can touch the bridge by directly standing on the abutments. They said that there was insufficient equipment to transport them to reach the middle of bridge spans. Based on general human behavior, contractors may do their jobs corresponding to inspectors' attitudes of executing their inspections.

6.3.2 Layout

To verify the above assumption, within one bridge, the measurements were broken into two main groups: 1) Abutment area, and 2) Middle span area. The data from these two groups were compared. Steel bridges are complex structures in terms of painting construction. Even on one section of a bridge member, the applicability varies from one area to another. To investigate the quality distribution within a bridge, in addition to abutment/middle areas, the data were also grouped based on the geometry of beam configurations. Currently, "I-shape" beams are the most popular in bridge constructions. Therefore, the components in the "I" beam were adopted as a factor with seven levels in the study. The components broken down in a "I" beam section are shown in Figure 6-1.

(1): Bottom of Upper Flange
(2): Web
(3): Top of Lower Flange
(4): Edge of Flange
(5): Bottom of Lower Flange
(6): Diaphragm (Bracing or Stiffener)
(7): Bolt

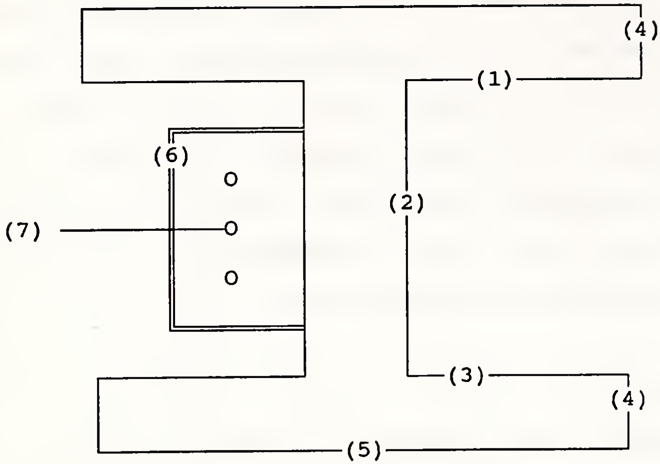


Figure 6-1: Components for I-beam

6.3.3 Design of the Experiment

To investigate the distribution of quality for existing painting constructions, the method named "Experiment Design" was applied in the data analysis phase. When the researchers started to collect data, the underlying quality distributions (tendencies) were totally unknown to the researchers. As mentioned in the previously section, three hypotheses in the experimental design were:

1). "Bridge" is a factor where qualities are different,

2). "Area" is a factor where qualities are different, and

3). "Component" is a factor where qualities are different.

From the initial data analysis, it was found that "area" and "component" factors for shop paintings were not significant because the working conditions and applicabilities in shops are more controlled than those in fields. In shop painting, the beams are set on the shop floors, all areas of the beam can be easily and equally painted. The researchers did not see any reason that the quality on the middle area of the beam will differ from the end area. On the other hand, painting is very sensitive to the working conditions in the field. The variation of applicability for field painting will make the quality differ in distinct areas/components within a bridge. Thus, field painting data were used in the "experiment design."

Measurements were randomly taken and grouped in components. The data from the same bridge are grouped as one block. In addition, Abutment/Middle areas, and 7 components are classified in the data layout shown in Figure 6-2. The measurements were taken at construction sites. The designs of bridges are different. The numbers of measurements cannot be controlled to be equal, as they can be laboratories. Therefore, the numbers of measurements in each cell of the layout are not the same. This design of experiment is considered an "INCOMPLETE UNBALANCED DESIGN."

Thousands of measurements of distinct bridges, areas and components were taken. The data analysis was done with the software named "SAS." The results are shown in Appendix 4-2.

BRIDGE (BLOCK)																			
		1		2		3		4		5		6		7		8		9	
AREA		A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
C O M P O N E N T	1																		
	2																		
	3																		
	4																		
	5																		
	6																		
	7																		

Figure 6-2: Layout of the Experimental Model

6.3.4 Findings and Inferences

The findings and subsequent inferences obtained from the experimental design are summarized below:

1). The "area" factor is significant. It implies that the quality on the abutment areas is potentially different from the middle span areas. The statistical parameters of the data are summarized in Table 6-5. The table shows that the mean value of the film thickness for the abutment areas is 7.53 mils, while for the middle areas it is 6.06 mils. In other word the average film thickness in middle areas is less than that in the abutment areas by an average of 1.46 mils. The difference is remarkable. It suggests that the thicknesses of painting around the middle areas do have a strong tendency to be thinner than those around the abutment area.

SNK Grouping	Mean	N	SECTION
A	7.52585	4200	Abutment Area
B	6.06250	6280	Middle Span Area

Table 6-5 : Summary for Abutment versus Middle Area

2). The "component" factor is likewise significant. Table 6-6 shows the numbers of measurements, the ranks, the mean values and the Student Newman Keuls (SNK) Grouping of the seven components. From the SNK test, it was apparent that not all of the components have significant difference in quality. Table 6-6 shows that their film thicknesses can be divided into four groups: A, B, C, and D. That is, we cannot deduce that the film thicknesses within one group are different statistically; even their mean values are different. In the contrast, the qualities from distinct groups potentially differ.

3). The "W" test from the SAS package shows that distribution of the data within each cell in the layout (Figure 6-2) is nearly normally distributed. Based on this finding, acceptance plans can be developed where normality is required.

SNK Grouping		Mean	N	Component
	A	7.29287	272	Bolt
	A			
	A	7.28847	1403	Edge of Flange
	A			
B	A	7.14100	1584	Diaphragm (Bracing or Stiffener)
B				
B		6.99977	1732	Top of Lower Flange
	C	6.47972	1861	Bottom of Lower Flange
	C			
	C	6.42686	2082	Web
	D	5.56098	1546	Bottom of Upper Flange

Table 6-6: Summary Table for different Components

4). A cross-reference for both "area" and "component" factors is shown in Table 6-7.

COMPONENT	Abutment Area MEAN	Middle-Span Area MEAN
(1): Bottom of Upper Flange	6.36	4.89
(2): Web	7.01	6.07
(3): Top of Lower Flange	8.00	6.23
(4): Edge of Flange	8.33	6.52
(5): Bottom of Lower Flange	7.18	5.92
(6): Diaphragm	8.74	6.35
(7): Bolt	12.50	7.14

Table 6-7: Cross reference for both "area" and "component"

Figure 6-3 shows a comparison for the abutment and middle span area illustrating that the two lines corresponding to abutment and middle areas go up and down coincidentally. These two lines can be considered to be approximately parallel. It implies that within the abutment and middle area factors, the

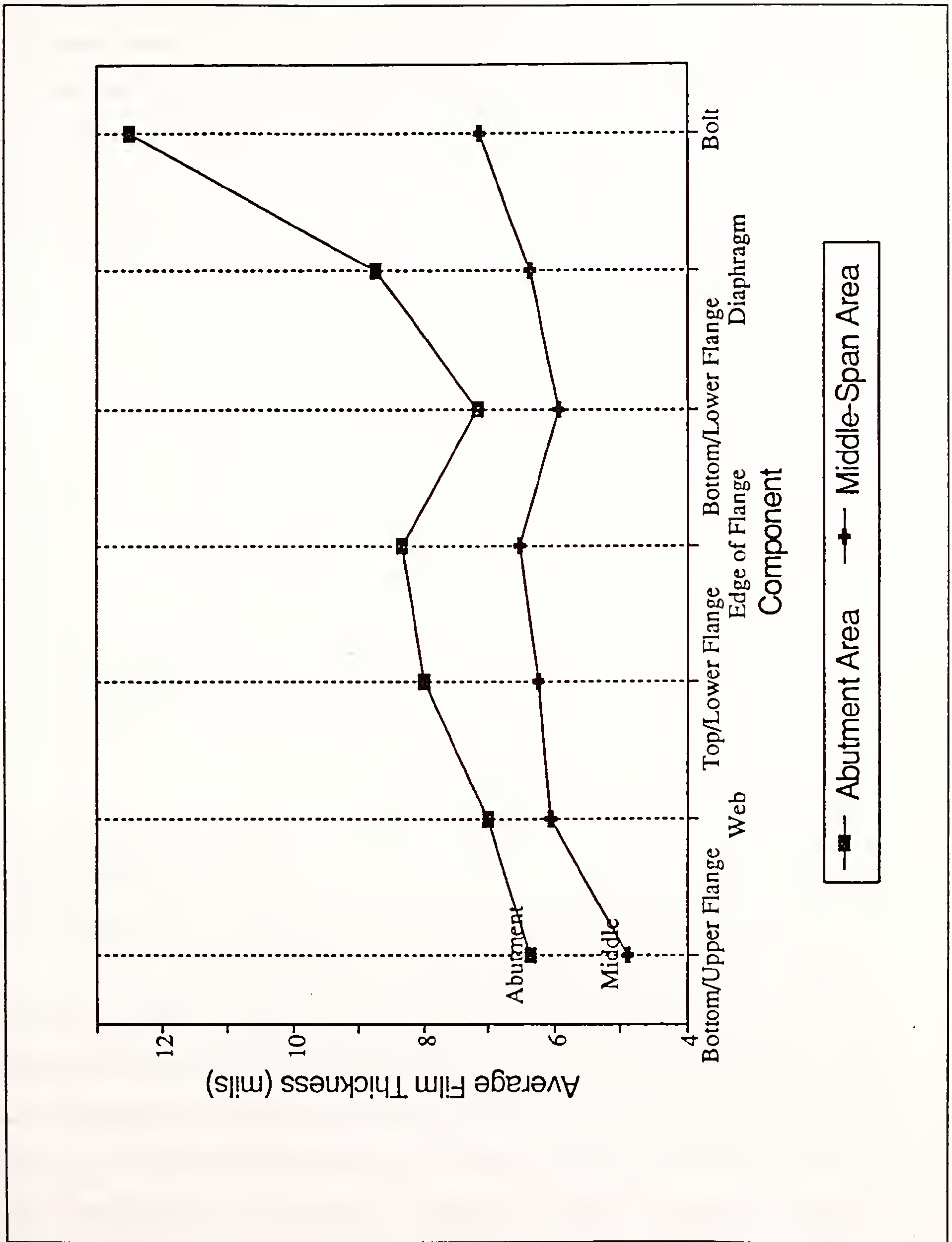


Figure 6-3: Comparison Chart for Abutment and Middle Span Areas

7 components have the same trend of quality distribution. In other words, potentially, the average DFT in the middle areas of the bridges is less than that in abutment areas regarding any one of the 7 components. No matter in which components, the painting thicknesses tended to be thinner in the middle span areas than in the abutment areas. Figure 6-3 supports the previous inference.

6.4 Conclusion

1). A realistic specification is necessary. No single project in the data analysis reached a perfect quality level conforming to 100% of the specification. In contrast, the percent of defective is much higher than the researchers' previously imagined. A specification which just specifies the minimum film thickness, or the average minimum DFT is insufficient. Reasonable quality levels and allowable percents of defective are necessary in QA specifications.

2). A high percentage of defective quality occurred in several states. This suggests there is a serious problem of inefficient enforcement of inspections. To solve this problem, inspector training programs should be supported.

3). Particular care should be taken to improve the painting quality by setting enhanced acceptance plans. The results from the experimental design show that the painting thicknesses in the middle span areas do tend to be thinner than those in the abutment areas. This phenomenon should be revealed to

inspectors in training programs. In this way, the inspectors may obtain stronger motivation to access the middle areas where the painting quality is currently apt to be deficient.

Chapter 7

Acceptance Sampling Plans (ASP)

7.1 Background

An acceptance sampling plan (ASP) is an application of statistics to quality assurance. The key function of the ASP is to guide the decision between accepting or rejecting finished products. There are several ways to categorize the acceptance sampling plans. In terms of the number of samples taken, the ASP's can be classified as single or double sampling. By the way the sampling information is utilized, ASP's can be classified as an attribute or variable sampling. In the following sections the terms, Lot, Sample Size, Single/Double Sampling, Attribute/Variable Sampling, Operating Characteristic Curve (OC curve), Producer's-Owner's Risk, and Quality Index are explained.

7.1.1 What is a lot? What is the sample size?

A "lot" is the basic unit of acceptance plans. Acceptance or rejection decisions are made within the lots. On many occasions, to reduce the costs of making a wrong decision from the acceptance plan, the whole finished product is divided into several small groups which are designated as lots. For instance, one or several members, or all the members of the bridge structure can be treated as a lot.

The number of the measurements is called sample size and designated as "n." Within a lot, one or several measurements are taken. All these "n" measurements are grouped and called "one sample" (James L, Burati, Jr., and Charles S. Hughes, 1990a).

7.1.2 What is Single or Double Sampling?

In single sampling, samples are taken only once and the decision to accept or reject the lot is made based on this one-time sampling. On the other hand, a double sampling plan is one that first uses a smaller sample size. If the information from the first sampling shows that the product is obviously conforming with the specified requirements, then the lot is accepted. However, if the first sampling shows that the product is obviously not conforming, then the lot is rejected. If the measurement results are between these two situations, and conformance is not clear, a second sampling is done to decide whether the lot will be accepted or rejected. The advantage of double sampling compared with single sampling is that it generally requires smaller sample sizes on the average to obtain the same efficiency as in single sampling plan (Wadsworth, M. Harrison and Stephens, Kenneth S. A. and Godfrey, Blanton 1986a).

7.1.3 What is Attribute or Variable Sampling?

Sampling plans also can be categorized as attribute sampling, or variable sampling. A distinguishing characteristic for variable sampling is the requirement of calculating the standard deviation

(SD) which can depict the finished product's variations. If the inspectors need to calculate SD in the sampling plan, the plan is a variable sampling plan, otherwise, it is an attribute sampling plan.

An attribute sampling plan usually produces one of two results -- the individual measurement in the sample either conforms or does not conform with the specified attribute. The following example is used to illustrate attribute sampling. INDOT's specifications require that the measurements of primer film thickness should be no less than 2.5 mils. Film thickness measurements from one lot might be 1.0 and 2.51 mils and measurements from a second lot 2.48 and 3.5 mils. Using the attribute sampling method, the results are the same for both lots because one out of two measurements is non-conforming; both would be considered 50% out of limits. Intuitively, it is obvious that the second lot with readings of 2.48 & 3.5 mils has a higher potential for satisfying the required lower limit of 2.5 mils. However, with an attribute sampling plan, the two sets of readings are the same; both are 50% out of limits. To avoid this weakness, a variable sampling plan can be used.

A variable sampling plan makes use of more relevant details. Instead of just determining whether an individual sample is within the specified limits, variable sampling utilizes the available data to estimate and represent the underlying population. After the overall population is estimated, a more precise estimated percent of non-conformance can be acquired. This statistical sampling method allows one to obtain the same level of discrimination power

on a smaller sample size "n" (Wadsworth, M. Harrison and Stephens, Kenneth S. A. and Godfrey, Blanton, 1986b).

7.1.4 What is the Operating Characteristic Curve (OC Curve)?

"One of the most useful considerations of a sampling plan is its operating characteristic function. Whenever a statistical sampling is derived, its description is not complete until its OC function or OC curve has been described" (Wadsworth, M. Harrison and Stephens, Kenneth S. A. and Godfrey, Blanton, 1986a).

OC curve is the curve that shows the probability of lot acceptance based on the various quality levels. Figure 7-1 is an example of an OC curve. It shows that when the underlying quality level of the lots is 10% defective (or say 90% conforming), with the specified requirements, by applying a specific acceptance plan, it can be assumed that this lot will be accepted with the chance of 95% or rejected with the probability of 5%. When the underlying quality level, percent of defective, goes up to 30% defective, the chance of accepting the lot would decrease to 5% accordingly. If the acceptance plan changes, its OC curve will change also. Thus, by setting a proper acceptance sampling plan for lots with different quality levels, the probability of accepting or rejecting the lots could be predicted precisely.

7.1.5 What is Producer's/Owner's Risk?

Contractor-supplied products that the highway agency is willing to accept are designated as acceptable quality level (AQL).

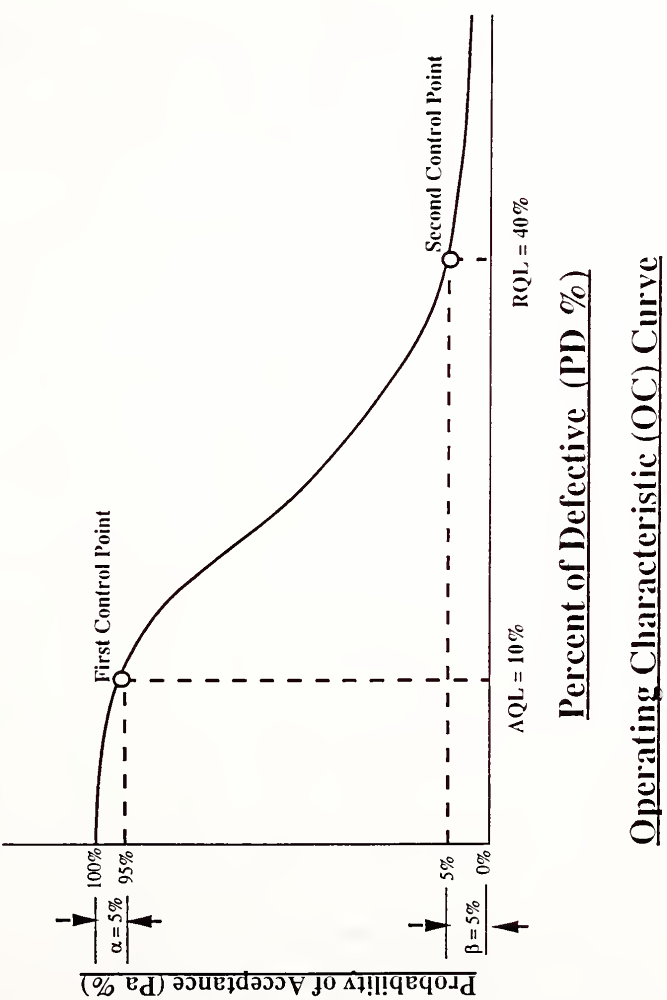


Figure 7-1: Typical Operating Characteristic (OC) Curve

However, because of the variation of the sampling, it is not 100% guaranteed that all the samples taken from this product will lead highway agencies to accept the product.

Products that highway agencies are very sure to reject are designated as rejectable quality level (RQL). Likewise, it is not 100% guaranteed that this defective product will be rejected based on the samples taken from the product

The chance of rejecting products with the acceptable quality level (AQL) is the producer's risk and is designated as alpha (α). The probability of accepting products with the rejectable quality level (RQL) is the owner's risk and is designated as beta (β).

Statistical theory says that a more precise estimate of the quality can be obtained with a larger sample size, thus reducing the risk of making a wrong decision. However, the larger sample sizes will increase the cost of the inspections. How can people strike a balance between accuracy and cost? The solution is to analyze and control the risk for making a wrong acceptance decision. Thus, many of the acceptance plans are developed based on controlling α and β risks. In other words, these acceptance plans are set to control the OC curve.

7.1.6 What is the Quality Index?

Quality Index is a parameter used to check with a prepared table for estimating the percent of defective. Because the sample size for each lot is likely to be small, and because the normal distribution is only appropriate for sample sizes of $n > 30$, to

estimate the percent out of the lower limit (or upper limit), the non-central t distribution is utilized (James L, Burati, Jr., and Charles S. Hughes, 1990b). Thus, instead of Z() value, the Q() value, which is called Quality Index, is used to obtain the percent of defective. The table for quality index is shown in Appendix 7-1. For example, assume the lower limit is 2.5 mils, sample size n is 10, the estimated mean value of the film thickness is 3.4 mils, and the estimated standard deviation (SD) is 0.8 mils. By the formula:

$$QL = \frac{\overline{X} - L}{\sigma} \approx \frac{\overline{X} - L}{SD}$$

$$QL = \frac{3.4 - 2.5}{0.8}$$

$$QL = 1.13$$

By checking the Q() value of 1.13 at n = 10 in the quality index table (Appendix 7-1), the estimated percent of defective (PD) is 12.80%.

7.2 Acceptance Sampling Plans (ASP's)

In painting construction, there are many parameters for setting the acceptance criteria for paint film thickness. The mean value of the film thickness, the variation of film thickness, or the percentage of the film thickness out of some specified limits could be used to evaluate the painting quality. Another approach would be to indicate that two or three of these three parameters

combined should meet the required limits. Percent of defective (PD), or the percent within the specified limits (PW) would be used to determine quality levels of lots. The relation between PD and PW is "PW = 1 - PD" (James L, Burati, Jr., and Charles S. Hughes, 1990c).

Acceptance plans in quality assurance programs vary because different statistical theories and combined quality parameters are applied to derive the decision criteria. Four different methods are discussed in the following sections. They are:

1. Variable Sampling with Risk Control
2. Attribute Double Sampling
3. Variable Sampling without Risk Control
4. Attribute Proportion Single Sampling.

7.2.1 Variable Sampling with Risk Control

Variable sampling with risk control is derived by controlling two points that correspond to AQL and RQL on the OC curve. The following example is used to demonstrate this method. Assume that there are two lots that need to be inspected. Currently, the highway agency's specification requires that the lower limit (L) for the primer film thickness is 2.5 mils. A film thickness less than (L) 2.5 mils would be rated as nonconforming or defective. Suppose, the first lot (group #1) has an acceptable quality level (AQL) of 10% defective, and the second lot (group #2) has a rejectable quality level (RQL) of 30% defective. If the highway agency would like to design an acceptance plan so that the

producer's risk (α) is 5% and the owner's risk (β) is 5%, the designed acceptance plan would lead them to decide to accept the first lot with the probability of 95% (5% probability of rejection), and accept the second lot with the probability of only 5%.

Figure 7-2 shows the underlying populations of the film thicknesses for the two lots. In Figure 7-2, u1 and u2 are the average film thicknesses for the population group #1 and #2 respectively. The percent of defective for each AQL is 10% and RQL is 30% respectively.

After samples of the size "n" are taken from group #1 and the data are calculated and the sample mean of group #1 noted is $\overline{X}_1$. By repetitive sampling (central limit) theory, the unbiased estimate of $\overline{X}_1$ is expected to be equal to u1, and the sample standard deviation is $\sigma(\overline{X}_1)/\sqrt{n}$. Likewise, the sample taken from group #2 would have $\overline{X}_2$ equal to u2 and the sample standard deviation $\sigma(\overline{X}_2)/\sqrt{n}$ (Figure 7-3).

Given the lower limits L=2.5 mils for setting up an acceptance plan which will comply with AQL=10%, RQL=30% , α=5% and β=5%, the questions become:

1) How large should the sample size n be?

2) What is the value of the parameter W?

W is the criteria used to check against the sample mean, $\overline{X}$, for making the decision of accepting or rejecting the lot. In other words, for a sample of size n, if: $\overline{X} \geq W$, the lot is accepted. If however, $\overline{X} < W$, the lot is rejected (see Figure 7-3).

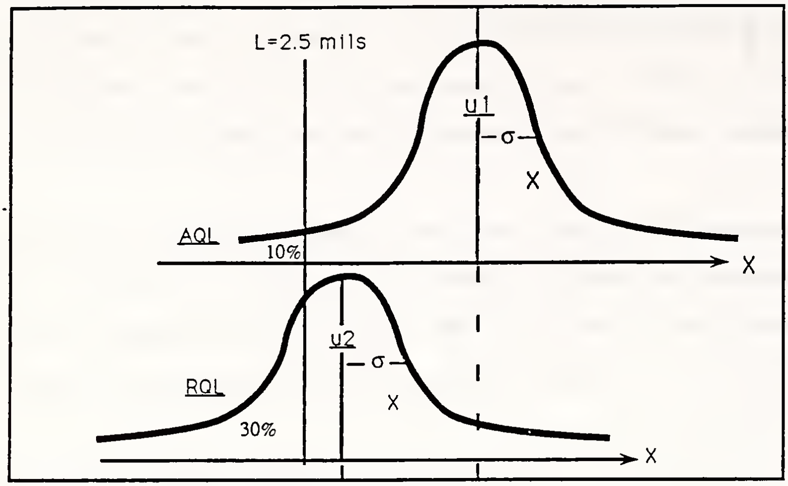


Figure 7-2: Distribution of Population (X)

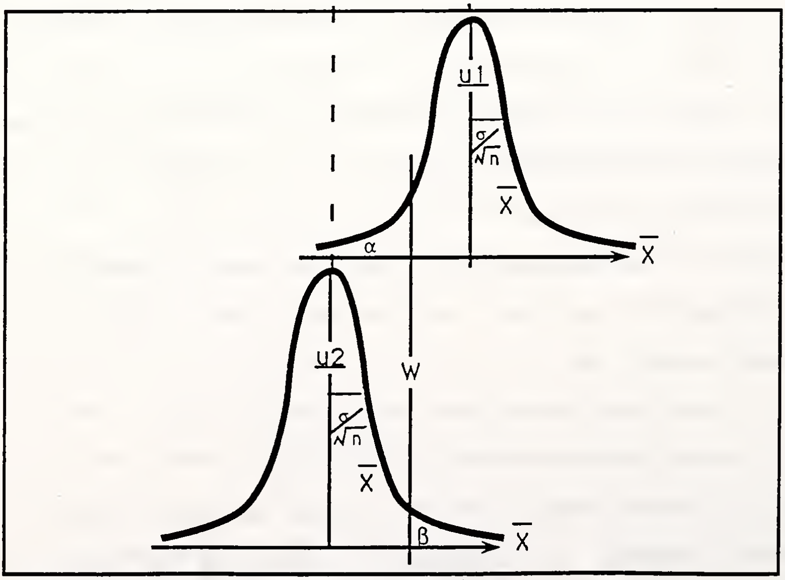


Figure 7-3: Distribution of Sample Mean $(\overline{X})$

Figure 7-2/3: Population and Mean Distribution for AQL & RQL.

To derive the formula for n and W, an intermediate parameter "k," which connects "n" and "W" is introduced.

The notations used are:

n is the desired sample size.

k is an intermediate parameter to connect n and W.

W is the decision parameter for checking with the sample mean.

Z() is the value found in the normal distribution table (Please see Appendix 7-2).

SD is the estimated standard deviation obtained from the sample.

$\overline{X}$ is the sample mean.

L is the specified lower limit (e.g. Current L for primer is 2.5 mils).

Equations for "k" and "n" are shown as follows. Detailed derivation is presented in Appendix 7-1 (Burr W. Irving 1976b):

$$k = -\frac{Z(\alpha) * Z(RQL) + Z(\beta) * Z(AQL)}{Z(\alpha) + Z(\beta)}$$

$$n = \left(\frac{k^2 + 2}{2}\right)\left(\frac{Z(\alpha) + Z(\beta)}{Z(AQL) - Z(RQL)}\right)^2$$

$$W = L + k * SD$$

With the above three equations, the required sample size n, and the intermediate parameter k can be obtained. After the sample is taken, the sample mean $\overline{X}$ and standard deviation SD are calculated. Given L, k, and the available SD, the decision parameter W is obtained. By checked $\overline{X}$ against W, an acceptance decision can be made as mentioned above.

Occasionally, the estimated percent of defective is also of interest. As mentioned previously, because the sample size for each lot is likely to be small, and because the normal distribution is only appropriate for small sizes of $n > 30$, to estimate the percent out of the lower limit, the non-central t distribution is utilized. Instead of Z() value, the Q() value, which is called Quality Index is used to obtain the percent of defective. Thus, the first step is to calculate the Quality Index for the lower limit (QL) which is shown as follows:

$$QL = \frac{L - \bar{X}}{\sigma} \approx \frac{L - \bar{X}}{SD}$$

The second step is to find the Quality Index for the lower limit (QL) in a prepared quality index table (Appendix 7-1); then the percent defective can be easily obtained. Some versions of quality index tables supply the percent within limit (PW); others supply the percent of defective. As mentioned before, the relation between PD and PW is "PW = 1 - PD." A flow chart showing the whole operation of this method is attached in Appendix 7-3.

Example:

Given that the lower limit for the primer film thickness is 2.5 mils, INDOT would like derive an acceptance plan to include the following conditions:

AQL= 10% = 0.1 ,and α = 5%

RQL= 40% = 0.4 ,and β = 5%

Thus, (from the normal distribution table in Appendix 7-2)

$$Z(AQL) = Z(0.1) = -1.29$$

$$Z(RQL) = Z(0.4) = -0.26$$

$$Z(\alpha) = Z(\beta) = Z(0.05) = -1.64$$

By inserting the above numbers into the previous equations:

$$\mathbf{k} = -\frac{Z(\alpha) * Z(RQL) + Z(\beta) * Z(AQL)}{Z(\alpha) + Z(\beta)}$$

$$= -\frac{-1.64 \times -0.26 + -1.64 \times -1.29}{-1.64 + (-1.64)}$$

$$\mathbf{k} = 0.775$$

$$\mathbf{n} = \left(\frac{k^2 + 2}{2}\right)\left(\frac{Z(\alpha) + Z(\beta)}{Z(AQL) - Z(RQL)}\right)^2$$

$$= \left(\frac{0.775^2 + 2}{2}\right)\left(\frac{-1.64 + -1.64}{-1.29 - (-0.26)}\right)^2$$

$$\mathbf{n} = 13.18$$

The sample size, n = 13.18, should be a whole number, so that n is rounded up to 14. With the above information, INDOT can specify the acceptance plan for primer film thickness as follows:

*The lower limit (L) for the dry film thickness of primer is 2.5 mils. In each lot, a sample of size 14 will be taken by inspectors. The sample mean is $\bar{X}$; the estimated standard deviation is SD. W = 2.5 + 0.775 * SD.*

If $\bar{X} \geq W$ ==> Accept the lot

If $\bar{X} < W$ ==> Reject the lot

The risk control points in this example are:

Acceptable Quality Level (AQL) = 10%

Rejectable Quality Level (RQL) = 30%

Control the Producer's Risk (α) = 5%

Control the Owner's Risk (β) = 5%

Assume the inspectors take the sample with size n=14, and get $\overline{X}$= 3.7 mils, and SD = 1.5 mils.

then,

$$W = L + k * SD$$
$$= 2.5 + 0.775 \times 1.5$$
$$= 3.665$$

The acceptance parameter W = 3.665, and the acceptance rules are:

If $\overline{X} \geq W = 3.665$ ==> accepts the lot

If $\overline{X} < W = 3.665$ ==> rejects the lot

Here, sample mean $\overline{X}$ is 3.7 mils which is larger than W = 3.665. Thus, the inspectors should accept this lot.

If the percent out of the lower limit is desired, the lower limit Quality Index (QL) is then calculated:

$$QL = \frac{\overline{X} - L}{\sigma} \approx \frac{\overline{X} - L}{SD}$$

$$= \frac{3.7 - 2.5}{1.5}$$

$$= 0.8$$

For n = 14, QL in a prepared quality index table (Appendix 7-1), the estimated Percent of Defective is 21.5%. This value may be recorded for future utilization with an adjustable pay schedule (Willenbrock, H. Jack and Kopac A. Peter, 1977).

7.2.2 Attribute Double Sampling

In double sampling, if the first sampling has a highly conforming result, no further sampling is necessary. Likewise, if the first sampling comes out with a very poor conforming result, the rejection decision can be made already. If the first sampling falls between obvious-acceptance and obvious-reject, a second sampling is taken. Compared with single sampling, the advantage of double sampling is that it needs smaller sample sizes on the average to obtain the same efficiency as in single sampling plan. As explained previously, attribute sampling does not supply as much information as variable sampling. To compensate for this the deficiency, a larger sample size is required to attain the same power as variable sampling for distinguishing the quality. However, attribute sampling is easier to operate. This makes it easy to apply the double sampling procedure in the painting construction.

Theory

Double sampling plans utilize two sample sizes along with two sets of acceptance-rejection parameters. The sampling plan calls for the inspectors to take the sample size of n1. If the number of nonconforming measurements is equal to or less than the first

acceptance number, c1, the lot is accepted. If the number of nonconforming units is equal to or greater than the first rejection number, r1, the lot is rejected.

If the nonconforming units fall between c1 and r1, a second sample size of n2 is taken. Then, if the total nonconforming items from the n1+n2 measurements are less than or equal to the second acceptance number c2, the lot is accepted. (Please see the flow chart of the operation of this method in Appendix 7-3)

To sum up , the notations used are:

n1 : first sample size

x1 : nonconforming items found in the first sampling

c1 : first acceptable number

r1 : first rejectable number

n2 : second sample size

x2 : nonconforming items found in the second sampling

c2 : second acceptable number

The procedures of this method are:

if $x1 \leq c1$ then accept the lot

if $x1 \geq r1$ then reject the lot

if $c1 < x1 < r1$ then second sample of size n2 should be taken

When the second sampling is necessary, continue the following processes:

if $x2+x1 \leq c2$ then accept the lot

if $x2+x1 > c2$ then reject the lot

According to the sampling theory, if the lot size is finite and should be counted, the hyper-geometric distribution should be used to describe the probability of the sampling. One the other hand, if the lot size is much larger than the sample size, the binomial distribution should be used (Burr, W. Irving, 1976a). In inspecting the painting construction, almost infinite numbers of dry film thickness (DFT) measurements can be taken within one piece of the painted structure member. Consequently, the lot size for the DFT sampling is regarded infinite. However, only a few measurements are usually taken to define the quality. Compared to the sample size, the lot size is very large. For this reason, the binomial distribution is used to develop the sampling plan.

The notations used here are:

pd : Underlying percentage of nonconforming (percent of defect)

n : sample size

x : number of nonconforming found in the sample

With the binomial statistics, the probability for getting x nonconforming items under the sample size of n is (Wadsworth, M. Harrison and Stephens, Kenneth S. A. and Godfrey, Blanton, 1986c):

$$P(x) = \frac{n!}{x!\ (n-x)!}\ pd^{x}\ (1-pd)^{(n-x)}$$

Thus, the probability for a lot to be accepted (Pa) is derived as follows:

Pa = the Probability for a lot to be accepted at first sampling

+ the Probability for a lot to be accepted at second sampling

$$
\begin{aligned}
Pa \quad = \quad & P(x1 \le c1) \\
+ \quad & P(x1 = c1+1) \times P(x2+x1 \le c2) \\
+ \quad & P(x1 = c1+2) \times P(x2+x1 \le c2) \\
+ \quad & P(x1 = c1+3) \times P(x2+x1 \le c2) \\
+ \quad & \ldots\ldots\ldots \\
+ \quad & \ldots\ldots\ldots \\
+ \quad & P(x1 = r1-1) \times P(x2+x1 \le c2)
\end{aligned}
$$

$$
\begin{aligned}
Pa \quad & = + P(x1 \le c1) \\
& + P(x1 = c1+1) \times P(x2 \le c2-(c1+1)) \\
& + P(x1 = c1+2) \times P(x2 \le c2-(c1+2)) \\
& + P(x1 = c1+3) \times P(x2 \le c2-(c1+3)) \\
& + \ldots\ldots\ldots \\
& + P(x1 = r1-1) \times P(x2 \le c2-(r1-1))
\end{aligned}
$$

$$
\begin{aligned}
Pa \quad & = + P(x1 \le c1) \\
& + \sum_{i=c1+1}^{r1-1} P(x1=i)\ P(x2 \le c2 - i)
\end{aligned}
$$

In the double sampling acceptance plan, there are six variable parameters. They are n1, n2, pd, c1, c2, and r1. Because of the complicated calculation of the probability and so many parameters, no monograph or table is available for the method. To get the probability of acceptance under different combinations of these six parameters, a set of computer program codes can be used to solve the problem.

By using the computers to generate various possible combinations for the six decision parameters, a set of the decision parameters can be chosen. Appendix 7-6 shows the attribute double sampling plan using different combinations of decision parameters. However, because all of the decision parameters are integers, the AQL/α and RQL/β cannot be controlled. Therefore it is closed to a set of pre-decided AQL-α and RQL-β as illustrated in the variable sampling.

With this method no statistic background is necessary for inspectors to run the sampling plan. Furthermore, the acceptance decision can be made without any calculation. Thus an on-time decision can easily be obtained even when the inspectors are still on the cherry-picker where they take measurements.

Example:

If the INDOT would like to have:

AQL = 10% = 0.1 and α = 5%

RQL = 40% = 0.4 and β = 5%

From the computers' outputs, a set of parameters of

n1=n2=10

c1=1 ; r1=3

c2=4

is a candidate which closely matches the pre-set criteria.

This set of acceptance parameters will control the following conditions:

AQL= 9% = 0.09

RQL= 42% = 0.42

α = 5%

β = 5%

With the above information, INDOT can specify the acceptance plan for primer as following:

The lower limit (L) for the dry film thicknesses of primer is 2.5 mils. In each lot, first inspection sample of size 7 will be taken by inspectors and the number of nonconforming items found is designated as x1.

if $x1 \leq c1=1$ *then accept the lot;*

if $x1 \geq r1=3$ *then reject the lot;*

if $c1 < x1 < r1$ *then a second sample of size 7 should be taken*

Nonconforming items found in second sampling are designated as x2.

So, when x1+x2 nonconforming in the two samples of size n1+n2 are found.

if $x2+x1 \leq c2=4$ *then accept the lot*

if $x2+x1 > c2=4$ *then reject the lot*

The Risk Control Points are:

AQL= 9% = 0.09

RQL= 42% = 0.42

α = 5%

β = 5%

7.2.3. Variable Sampling without Risk Control

Currently, some of the highway agencies already adopted the statistic-acceptance specifications in the pavement area (Weed, M. Richard, 1989a). In these specifications, the sampling methods, sample sizes, and the rules for making acceptance decisions are all laid out. However, few of them do the risk analysis and control. If

the producer's risk α and the owner's risk β are not taken into account, a simplified method without applying advance statistics theory can be adopted. This method, using the quality index to estimate the percent of defect, was already discussed in section 2.1. In this method an allowable percent of defective (Apd) should be specified in the specification. After the data are collected by using the quality index, and by checking a prepared quality index table, the percent of defective (PD) of the lots can be obtained. Then, the estimated percent of defective (PD) can be compared with the allowable percent of defective (Apd) to make an acceptance decision. But, the sample sizes in this method are selected without theoretical support. That is, the α and β risks are not analyzed and controlled.

Theory

In this method, of variable sampling without risk control, an acceptance criterion called Allowable Percent of Defective (Apd) should be pre-specified by highway agencies. After the sample size is subjectively set, the percent of defective (PD) can be estimated by using Quality Index and the Percent of Defect Table to check the percent of defective.

The notations here are:

SD is the estimated standard deviation obtained from the sample.

$\overline{X}$ is the sample mean.

L is the specified lower limit (e.g. Current L for primer is 2.5 mils)

Let

$$QL = \frac{L - \bar{X}}{SD}$$

With a pre-prepared Quality Index Table (Appendix 7-1), the percent of defective (PD) or the percent within limit (PW) can be easily obtained. The relation between PD and PW is "PW = 1 - PD". Here, PD is used to check with the specified allowable percent of defective (Apd) which is pre-determined by highway agencies (Weed, M. Richard, 1989).

If $\quad PD \leq Apd \quad ==> \quad$ Accept the lot

if $\quad PD > Apd \quad ==> \quad$ Reject the lot

The corresponding operation flow chart can be in Appendix 7-3.

However, with this method there is no awareness of the probability of acceptance for different quality levels. In other words, the α and β risks are not analyzed or controlled. Thus, the INDOT and contractors have no idea about the probability of acceptance for a particular lot with a given quality level.

Example

If the highway agency considers that a sample size of 10 is a reasonable load for inspectors, then the agency just subjectively set the sample size n equal to 10.

A possible specification can be :

The dry film thicknesses of primer should be no less than 2.5 mils. That is, the lower limit (L) is 2.5 mils. The Allowable Percent of Defective (Apd) is 20%. In each lot, a sample of size 10 will be taken by inspectors. The sample mean is $\overline{X}$; the estimated standard deviation of the underlying population is SD. To estimate the percentage out of lower limit, Quality Index for Lower Limit is:

$$QL = \frac{L - \overline{X}}{SD}$$

by checking QL with the Quality Index table, the estimated percent defective (PD : percentage out of lower limit L) is obtained.

If PD $\leq$ Apd = 20 % ==> Accept the lot

if PD > Apd = 20 % ==> Reject the lot

Assume an inspector takes 10 dry film thickness readings (a sample size of 10) from a lot. If the sample mean of $\overline{X}$ is 3.39 mils, and the standard deviation of SD is 1.03 mils. If the Allowable Percent of Defective (Apd) is 20%. The Quality Index can be determined as follows:

$$QL = \frac{\overline{X} - L}{SD}$$

$$= \frac{3.39 - 2.5}{1.03}$$

$$= 0.86$$

From the Quality Index table (check at n = 10 and QL=0.86), PD is 19.81%. Since,

PD = 19.81% $\leq$ Apd = 20% ===> this lot will be accepted.

Again, if the sample mean of $\bar{X}$ is 3.05 mils, and the standard deviation of SD is 1.11 mils. Given the Allowable Percent of Defective (Apd) is 20%. The Quality Index:

$$QL = \frac{\bar{X} - L}{SD}$$

$$= \frac{3.05 - 2.5}{1.11}$$

$$= 0.495$$

From the Quality Index table (check at n = 10 and QL=0.49) the estimated PD is 31.72%.

PD = 31.72% > Apd = 20% ===> This lot will be rejected.

7.2.4 Attribute Proportion Single Sampling

If an attribute sampling is applied and the assistance of computers is not available, the Attribute Proportion Single Sampling method can be an option for setting the acceptance plan.

Theory

Here the notations used are:

n : sample size

p : underlying percentage (p) of defective of the lot

$\mu()$:   expect value

By the binomial statistic theory,

1. The distribution of percent of defective of the sample is:

   estimated $\mu(p) = p$

   estimated $\sigma_p = (p*(1-p)/n)^{1/2}$ (see Figure 7-4)

2. The underlying percentage of defective can be estimated within the Error Margin (h) for the confidence level of (α). That is, the real underlying percent of defective should fall within the range of "p ± h" with the chance of α.

   The binomial distribution shows that:

   $$h = Z(1-\alpha/2) * \sigma_p$$
   $$= Z(1-\alpha/2) * (p*(1-p)/n)^{1/2}$$

   Thus,

   $$n = \frac{Z^2(1-\alpha/2) * (p * (1-p))}{h^2}$$

   Insert respectively,

   h = 1%, 2%, 3%, 4%, 5%, ...

   p = 5%, 10%, 15%,.....

   α = 95%, 90%, 85%, 80%

into this formula, and the required sample sizes under different combinations of h, p, and α are obtained, which are shown in Appendix 7-4.

If a sample of size n is taken, the resultant percent of defective from the sample is (p), the estimated percent of defective is:

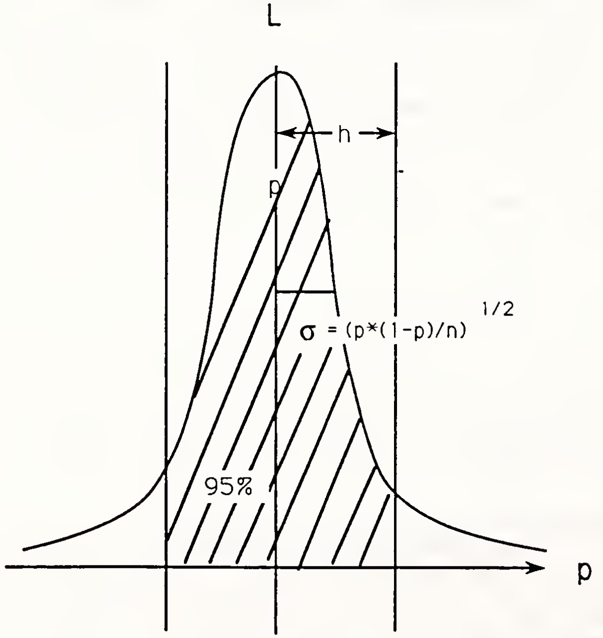


Figure 7-4: Error Margin for 95% Confidence Interval

$$p \pm h \text{ (error margin)}$$

$$p \pm Z(1-\alpha/2) * (p*(1-p)/n)^{1/2}$$

To control the error margin (h), by assuming a "p" value and changing the sample size n, at different confidence level $(1-\alpha)$, the desired error margin (h) can be obtained. On the other hand, if h, p, and $(1-\alpha)$ are pre-decided, the desired sample size can be derived by formula (Neter, John and Wasserman, William and Whitmore, G.A. ,1988a):

$$n = \frac{Z^2(1-\alpha/2) * p *(1-p)}{h^2}$$

Assuming that the INDOT would like to control the error margin to 5%, and a confidence level of $(1-\alpha) = 95\%$, the maximum percent of defective is specified as L=10%. If the underlying percent of defective is 10%, the required sample size is computed as follows:

$$n = \frac{Z^2(1-\alpha/2) * p *(1-p)}{h^2}$$

$$n = \frac{1.96^2 * 0.1(1-0.1)}{0.05^2}$$

$$= 138$$

For example, if the inspector takes n=138 measurements, and finds x=10 number of nonconforming items in the sample, the resultant

percent of defective is calculated by

$$p = x/n = 10 / 138$$

$$= 7.25\%$$

According to the previous rule,

If $p \leq L$ (10%) ==> Accept ;

If $p > L$ (10%) ==> Reject.

Here, p is 7.25%, which is less than 10%. The lot should be accepted.

With this theory, the accuracy to estimate the underlying population can be controlled by error margin (h). The smaller error margin (h) that is required, the larger the sample size (n) must be.

In bridge painting specifications, the highway agency can specify the allowable percent of defective (Apd) in the contract. By controlling the error margins, the required sample size can be obtained. If the resultant percent of defective ($p = x/n$) is smaller than the specified maximum, the lot will be accepted; otherwise, it will reject.

However, as mentioned before, the risk analyses are very important in the acceptance sampling plans. There is no direct information to control the producer's (α), and owner's (β) risks in this method. A derived extension is necessary to compensate for the deficiency.

The Extended Attribute Proportion Single Sampling

Two control points, are utilized to set the sample size n and decision parameters W which is used to check against the estimated percent of defective. These are: 1) the products with the AQL have the chance of (α) to be rejected, and 2) the products with the RQL have the chance of (β) to be accepted (See Figure 7-5). If a sample size of n is taken and x is the number of nonconforming items found in this sample, the percent of defective (p) is estimated by x/n. The distribution of percent defective of the sample is:

estimated $\mu(p) = p = x/n$

estimated $\sigma_p = (p*(1-p)/n)^{1/2}$

If $p \leq W$ ==> Accept

If $p > W$ ==> Reject

A flow chart illustrating the practice of this method is shown in the Appendix 7-3. Based on statistics:

the Probability of accepting RQL quality:

$$\frac{(W - RQL)}{(RQL*(1-RQL)/n)^{1/2}} = Z(\beta)$$

the Probability of Rejecting AQL quality is:

$$\frac{(W - AQL)}{(AQL*(1-AQL)/n)^{1/2}} = Z(1-\alpha)$$

where, Z() can be checked from the normal distribution table (Appendix 7-2).

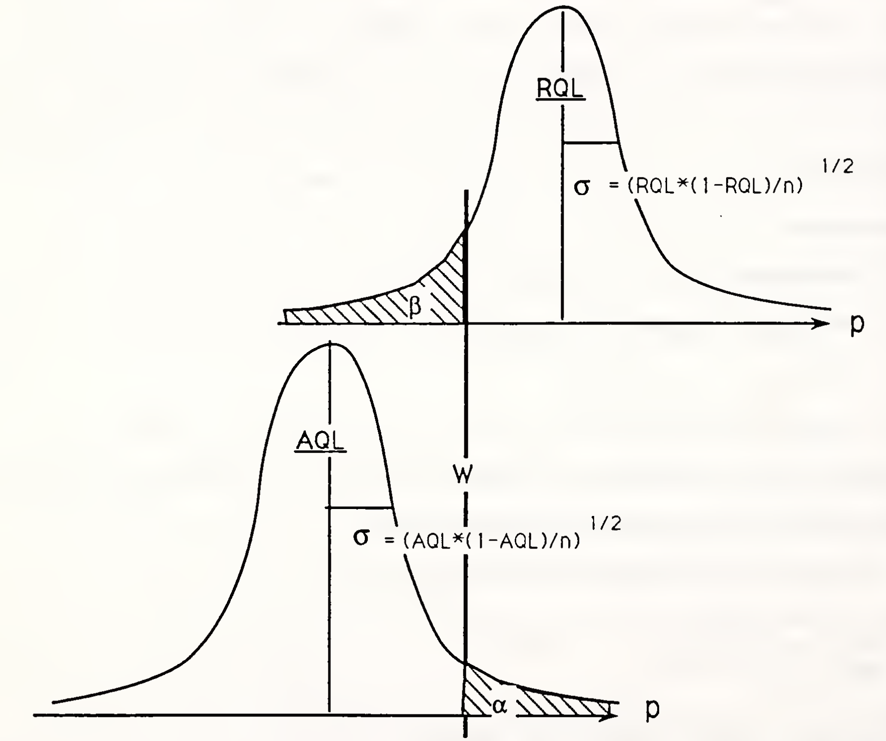


Figure 7-5: Proportion Distribution for AQL & RQL

For example, $Z(0.05) \approx -1.65$; $Z(.95) \approx 1.65$

Solve the above two system equations and get:

$$n = \left[\frac{Z(\alpha)*(AQL*(1-AQL))^{1/2} + Z(\beta)*(RQL*(1-RQL))^{1/2}}{(AQL - RQL)} \right]^2$$

$$W = AQL - Z(\alpha)*(AQL*(1-AQL)/n)^{1/2}$$

<< or, $W = RQL + Z(\beta)*(RQL*(1-RQL)/n)^{1/2}$ >>

With the above two equations, the sample size n, and decision parameters are obtained.

Example:

Assume INDOT would like to set the

Acceptable Quality Level (AQL) = 10%

Rejectable Quality Level (RQL) = 30%

Control the Producer's Risk (α) = 5%

Control the Owner's Risk (β) = 5%

Applying the formula:

$$n = \left[\frac{Z(\alpha)*(AQL*(1-AQL))^{1/2} + Z(\beta)*(RQL*(1-RQL))^{1/2}}{(AQL - RQL)} \right]^2$$

the required sample size is:

$$n = \left[\frac{-1.65*(10\%*(1-10\%))^{1/2} + -1.65*(30\%*(1-30\%))^{1/2}}{(10\% - 30\%)} \right]^2$$

$$n = 30$$

To get the Accept/Reject decision parameter W, apply the formula:

$$W = AQL - Z(\alpha)*(AQL*(1-AQL)/n)^{1/2}$$

$$W = 10\% - (-1.65) * (10\% *(1-10\%))/ 30)^{1/2}$$

$$= 17.91 \%$$

The estimated percent of defective is calculated by

$p = x/n$ (x is the number of nonconforming items)

If $p \leq W=19.71\%$ ==> Accept

If $p > W=19.71\%$ ==> Reject

With the above information, INDOT can specify the acceptance plan for primer film as follows:

The dry film thicknesses of primer should be no less than L which is 2.5 mils. In each lot, a sample of size 30 will be taken by inspectors. The number of defective from a sample is x. The estimated percent of defective is p = x/30.

If $p \leq W = 17.9\%$ ==> Accept the lot

if $p > W = 17.9\%$ ==> Reject the lot

INDOT already controls the following condition:

Acceptable Quality Level (AQL) = 10%

Rejectable Quality Level (RQL) = 30%

at AQL: probability of acceptance of the product is 95%.

(Producer's Risk α = 5%)

at RQL: probability of acceptance of the product is only 5%.

(Owner's Risk (β) = 5%)

Following the previous specifications, inspectors take n=30 measurements within one lot. Suppose nonconforming items "x" found in lot is 3. The estimated percent of defective is calculated as:

$$p = x/n$$

$$p = 3/30$$

$$= 10\%$$

Here, p (= 10%) ≤ W (=17.9%) ==> accept the lot.

Again, if it is, assume that there are 7 film thickness readings less than L=2.5 mils, the resulted percent of defective is calculated by:

$$p = 7/30$$

$$= 23.3\%$$

Here, p (= 23.3%) > W (=17.9%) ==> reject the lot.

7.3 Features for Different Methods

As explained earlier, the variable sampling provides more information than a mere determination in attribute sample does,

which is either "good" or "defective." Generally, the variable sampling efficiently utilizes the normal distribution to supply a more precise estimate of the percent of defective.

1. The variable Sampling with Risk Control method developed from a solid theory. The α and β risks are analyzed and controlled by the sample size n and an intermediate decision parameter k. However, more advanced statistical theory is involved in the derivation this method. Also, the Standard Deviation (SD) and Decision parameter W need to be calculated by inspectors. These are the weakness of this method.

2. Attribute Double Sampling involved the comparatively complex calculations. With the assistance of computers, the problem can be solved. As explained before, a larger sample size is needed to obtain the same power as the variable sampling method. Nevertheless, the use of attribute "Double" sampling reduces the sample size by dividing the sample phase into two stages. To make acceptance decisions, the inspectors should only count the number of defective. This easy-to-apply feature supplies an on-time decision and can be the inspector favorite.

3. The variable Sampling without Risk Control method does not analyze or control the α and β risks. However, this method is still adopted by many agencies because it involves a simple

theory. Besides, this method allows the highway agency to decide subjectively on the sample size.

4. The attribute Proportion Single method is an extension of the Error Margin method. However, this method to estimate percent of defective is not efficient.

A summary table comparing the four methods is attached in Appendix 7-5.

Chapter 8

Development of Adjustable Pay Schedule

8.1 Introduction

The Transportation Research Board has been supporting efforts of the FHWA for the development of an adjustable payment system for quality works (Riley, Orrin, 1991). An adjustable pay schedule system plays an important role in developing acceptance plans in highway construction. Currently, many highway agencies have adopted the concept of adjustable pay schedules into their specifications. If the products do not conform to the specifications, removal or reconstruction may be possible; in many cases, however, it can be more beneficial to the agency and less costly to the contractor to leave the products in place and pay the contractor a reduced payment. Because of the possibility of receiving less than the full bid price for lower quality work, contractors are compelled to pay attentions to maintaining the quality of their products; then the quality can be assured.

To develop adjustable pay schedules for painting construction, the characteristics related to the serviceability of corrosion protection functions should be defined. There are many parameters that specify the quality of the final painted products, such as surface preparation, paint materials, coating thicknesses, dry

spray, mudcracking, bubbling and so on. It is difficult to convert many of these parameters to a quantitative format. Among them, the coating thickness is easier to be quantified and is highly correlated to the serviceability. Currently, the measurement of Dry Film Thickness (DFT) is commonly used in steel bridge painting inspections to determine the quality of its corrosion protection.

For painting construction, the concept of adjustable pay schedules is totally new. In the past, for instance, if the thickness of the painting film did not meet the specified requirements, the contractor would be asked to add more paint to the existing coating, or to remove and repaint the structure. However, if additional paint is added on the existing film, the binding strength between the exiting and new paint is questionable. Its service life won't always be extended. Even when remeasurements show an increase in the film thickness, this does not mean that the quality is improved accordingly. On the other hand, the owners may insist that the nonconforming painted products be removed and repainted. It is a tremendous waste if the nonconforming painted product still has a significant period of service life. To solve the previous problems, adjustable pay schedules serve as possible solutions.

8.2 Four Approaches for Setting Adjustable Pay Schedules

Generally, four approaches can be used to develop the adjustable pay schedule including: 1) Product Cost, 2) Cost of

Quality Control, 3) Serviceability, and 4) OC curve (Willenbrock, H. Jack and Kopac A. Peter, 1977). These approaches are described in the following sections.

8.2.1 Product Cost Approach

With the product cost approach, the payment is reduced corresponding to the reduction in quality. According to Willenbrock, a heavier penalty may be imposed to attract the contractors' attention. As a result, the payment reduction should be greater than the reduction in the resultant cost of lower quality. However, regarding current contract system, few quality characteristics can be used in this approach because, in most cases, the contractor's real costs are actually unknown to the highway agency. The highway agency knows only the item bid prices, which include the cost of labor, equipment and overheads, as well as materials.

8.2.2 Cost of Quality Control Approach

In order to make the cost of the quality control approach workable, more efforts are needed to accumulate necessary data for determining the relation between "what the contractors spend on quality control" and "the resulting quality of the project." This approach will be implementable only when more cost data are available. However, the necessary efforts are considered to be low in terms of cost effectiveness.

8.2.3 Serviceability Approach

"Perhaps the most logical basis for establishing a defensible price-adjustment schedule is the selection of an adjustment in the unit price which is commensurate with the expected serviceability of performance of the finished product" (Willenbrock, H. Jack and Kopac, A. Peter, 1977). If the relation between quality characteristics and serviceability is clear, then a tabular format or formula can be provided as an index for the agency to pay for the product. So far, for concrete pavement constructions, several state highway agencies have used a serviceability approach for their price-adjustment pay schedule. But, in many cases, the relation between quality characteristics and serviceability are not clearly defined. As a result, few true performance related specifications have been developed (Bower, Dwight, 1991). In painting construction, there is no reliable formula to define the relationships among service life (performance) and quality parameters. Therefore, it is difficult to develop adjustable pay schedules using the serviceability approach.

8.2.4 OC Curve Approach

Originally, the OC curve was used to set up acceptance sampling plans. It can provide the analysis and control over the risks produced from sampling. The same concept can also be utilized to develop adjustable pay schedules. Once the sample size and the acceptance criteria have been established, the highway agency can use OC curves and the curves of expected payment to develop a

feasible adjustable pay schedule. There is no specific rule to decide the pay factor. A trial pay schedule should be designed initially. The trial pay schedule should receive feedback from both highway agencies and contractors. When agencies and contractors are both pleased with the pay factor curves, the schedule can then be incorporated into the specification. Researchers in this field have developed a linear function to define the pay factor for different percentage of defective for the concrete pavement construction (Weed, M. Richard, 1989a).

8.3 Methodology Used

Considering the difficulties for obtaining cost data, serviceability and OC curve approaches are more feasible in developing adjustable pay schedules for painting constructions. Detailed discussion is presented in the following sections.

8.3.1 Serviceability Approach

As mentioned before, the coating thickness is relatively easier to quantify. Also, it is highly correlated to serviceability. Figure 8-1 and 8-2 show the statistics describing the relative performance between zinc coating thickness and its corresponding expected service life. In these two figures, the estimated serviceability of zinc-coats under different atmospheres is supplied.

Estimated Life of Zinc-Coated Products in the Atmosphere (Year)						
Thickness	Rural	Tropical Marine	Temperate Marine	Suburban	Urban	Highly Industrial
3.60	50	40	35	30	25	15
2.30	35	30	25	20	17	9
1.80	25	20	15	12	10	7
1.10	10	8	7	5	4	3
0.66	7	6	5	4	3	2
0.44	5	4	3	3	2	1
Source: Zinc Control Corrosion 21-51-10m/71 Zinc Institute, Inc. New York, NY (1971)						

Figure 8-1: Zinc-Coating Thickness & Estimated Service Life

The data here present valuable information, showing that the estimated service life is approximately proportionate to the thickness of the zinc-coat. To justify this inference, a liner regression method was used to create a regression line that fits the data most exactly. Using the data for suburban areas as an example, with the least square regression method, it is easy to get a regression line that best fits the data. The comparative chart presenting the original curve and the regression curve is shown in Figure 8-3. The regression line in this figure is forced to pass the origin point because the coat thickness is very close to zero and the service life is assumed to be zero.

Figure 8-3 shows that the regression line is quite compatible with the original data curve. The variance between these two lines is assumed to be tolerable. The equation for the regression line is

Y (Years of Life) = 7.925 T (Thickness of the Film).

Likewise, this procedure can be applied to rural areas, tropical

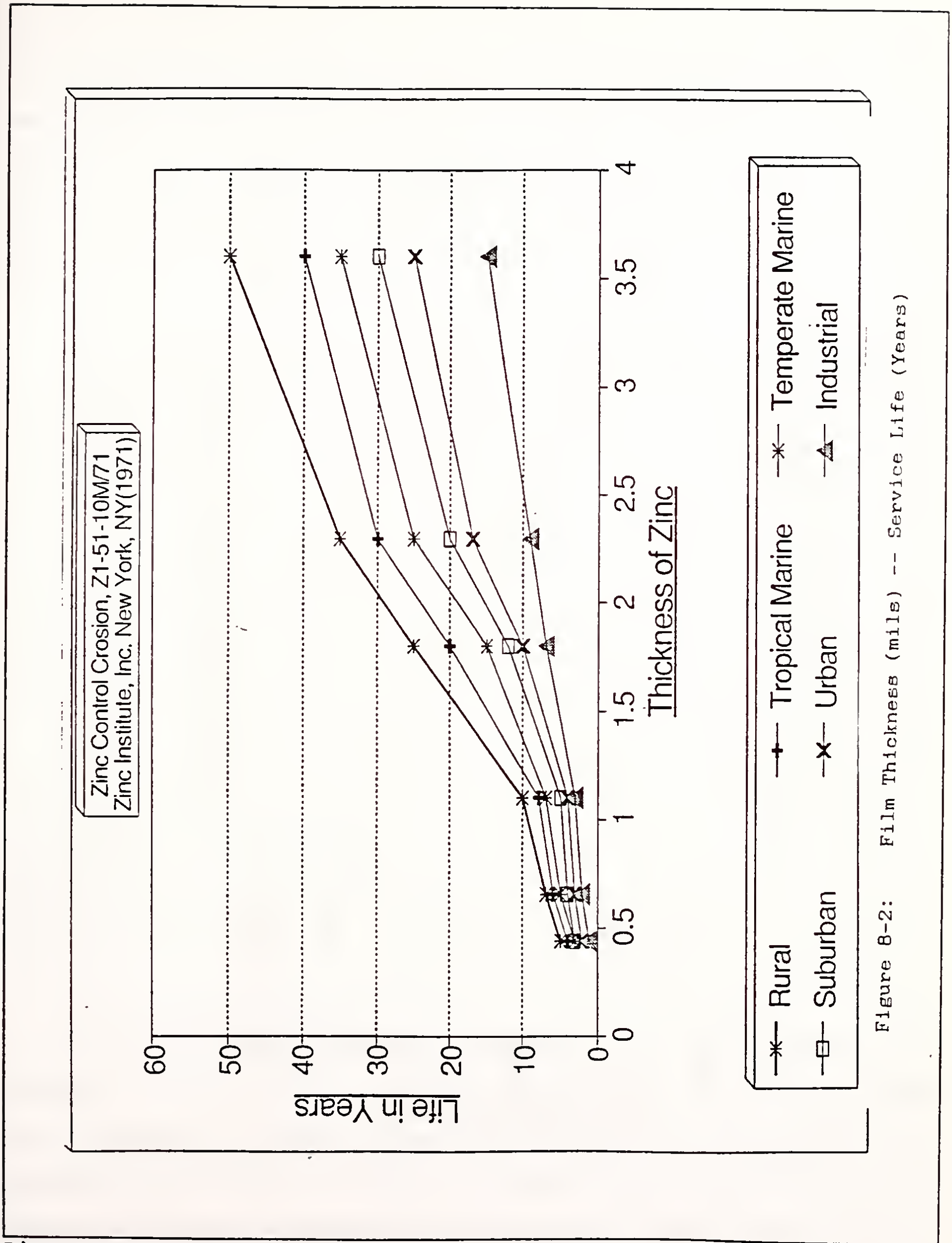


Figure 8-2: Film Thickness -- Service Life.

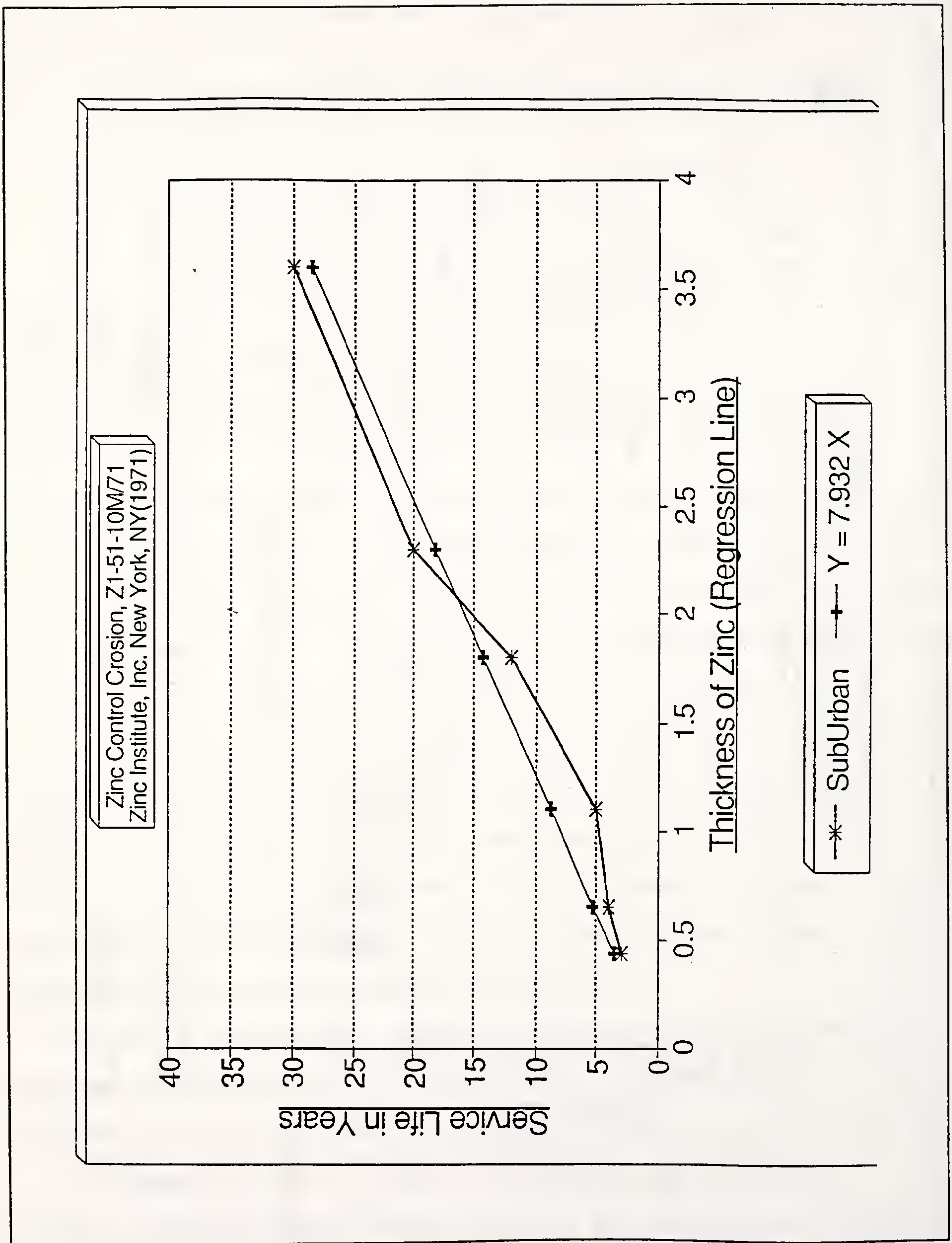


Figure 8-3: Linear Regression for Service Life in Suburban Areas

marine areas and industrial areas with the similar results, the only difference is the coefficient related to the slope of the regression line. For example, the slope coefficient for the Suburban area is 7.925 (Year/Mil). The coefficient for the Industrial area is 4.2 (Year/Mil), which is less than the Suburban area.

The above data are only general estimates because of the many companies producing different paint materials. The areas where paints are applied are also diverse. Plus, the development of new techniques in paint material industries can be so fast. As a result, it is difficult to predict the corrosion protective capability for specific paint materials. Furthermore, under dissimilar atmospheres the slopes of the service curve can be different. Thus, it is difficult to predict the slope coefficient in "Coating Thickness & Service Life Chart." Nevertheless, with the above analysis, we may well assume that the equation for coating service life is "$Y= C * T$". Let "C" be the coefficient of a specific zinc-coat corresponding to certain atmosphere and paint material. The "T" is the obtained coat thickness.

If the obtained coating thickness is $T1$ mils, then the estimated service life is $Y1= C*T1$ years. If the specified design coat thickness in the contract is $T2$ mils, then the designed service life is $Y2= C*T2$ years. IF the bid price is "B" dollars, then the unit service price based on designed life for one year is

B/Y2 (dollars per year). But, the obtained coating can actually serve Y1 years. As a result, the price for the product should be (B/Y2)*Y1 or in the form of B*(Y1/Y2), where (Y1/Y2) is considered as pay factor. The pay factor can be derived as:

$$\begin{aligned} PF &= [\text{ Actual Service Life / Designed Service Life }] \\ &= (Y1/Y2) \\ &= (C*T1 \,/\, C*\, T2) \\ &= (T1 \,/\, T2) \\ &= [\text{ Actual Thickness / Designed Thickness }] \end{aligned}$$

This shows that the pay factor is the "ratio" of coat thickness. Using this method, the average film thickness is employed as a parameter to obtain the pay factor (PF). However, there is a vital disadvantage in applying the above method. The variation of the film thickness is not considered in the formula. As long as the average film thickness can reach a certain value, the contractor may not maintain the uniformity of the film thickness. If this is the case, extra paint thickness may be applied on certain areas, and deficient paint thickness may applied on other areas. This may cause the premature failure of the painted structure. Therefore, another approach, utilizing the same concept of "OC curve," is proposed to set the adjustable pay schedule function.

8.3.2 OC Curve Approach

The serviceability approach does not insure that the resulting pay schedule will be either reasonable or readily acceptable by both the highway agency and the contractor. It is recommended that the OC curve approach should be adopted. Although the OC curve approach is not as logical as the other approaches, its primary advantage is that it provides a method by which the highway agency can define the desired payment based on the quality obtained. It is more likely to yield a pay schedule that will be accepted by all parties involved. In addition, for painting construction, many quality characteristics are non-quantifiable such as dry spray, bubbling, or mudcracking. These quality characteristics are not clearly defined so far. There is little information linking the service life to these non-quantifiable quality characteristics. For these reasons, visual inspections should be performed. This kind of inspection is attribute inspection, which can only be conforming or non-conforming. Thus, the service life equation is difficult to establish. Therefore the other option, the OC curve, is recommended for developing an adjustable pay schedule which can be preferred by more highway agencies (Weed, M. Richard, 1989b).

The parameter used to decide the pay factor is the percent of defective (PD). The procedures to compute the percent of defective for both attribute and variable sampling are explained in Chapter 7. Currently, a linear equation is used in the adjustable pay schedule (Weed, M. Richard, 1989b). To develop the curve for a pay

schedule, it is first necessary to determine the pay factors associated with two quality levels, Acceptable and Rejectable Quality Levels (AQL & RQL) in terms of percent of defective (PD). That is, the pay schedule function is determined by the two points of AQL and RQL as shown in Figure 8-4. The derived equation for pay factor, in terms of percentage, based on the two points of AQL and RQL, is:

$$PF = \frac{PF_{RQL} - PF_{AQL}}{RQL - AQL} (PD-AQL) + PF_{AQL}$$

The following numerical example is used to illustrate the computing, assuming that the conditions described in the Table 8-1 are a highway agency's criteria to set the pay factor function.

Quality Level	Percent Defective (PD)	Pay Factor (PF)
AQL	10 %	100 %
RQL	40 %	70 %

Table 8-1: criteria to set the pay factor function

The pay factor function could be :

$$PF = \frac{PF_{RQL} - PF_{AQL}}{RQL - AQL} (PD-AQL) + PF_{AQL}$$

$$PF = \frac{70\% - 100\%}{40\% - 10\%} (PD-10\%) + 100\%$$

$$PF = 110\% - PD$$

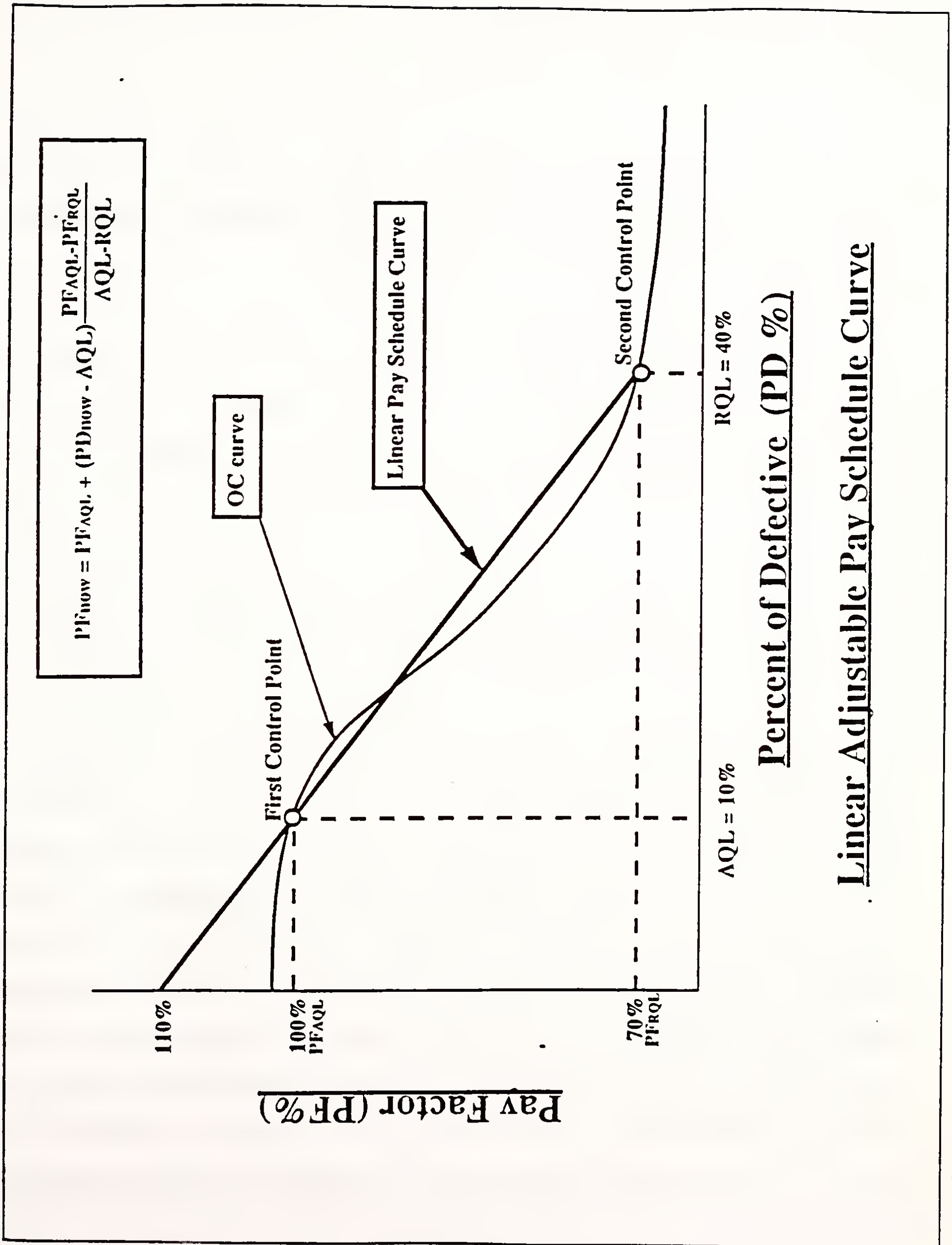


Figure 8-4: Linear Adjustable Pay Schedule

where

PF : is the Pay Factor, and

PD : is the Percent of Defective.

The initial privilege for deciding AQL and RQL and their corresponding pay factors, PF_{AQL} & PF_{RQL}, is left to the highway agency. But before the equation is adopted into specifications, it should satisfy all the parties involved.

When the researchers interviewed the highway personnel, this method was demonstrated. One of their responses was that they worried about the increased cost of adopting this method. In other words, the additional payment for higher quality products is their major concern. For this reason, the control of the maximum pay factor is proposed in the adjustable pay schedule. Currently the linear pay factor function only controls two points. The fist point is AQL-PF_{AQL} and the second is RQL-PF_{RQL}. The agency may not feel comfortable if the pay factor function does not control the maximum pay factor at the beginning of the development. However, the possible maximum pay factor is sensitive to how these two points are set. For instance, assuming that the quality of RQL is considered a very serious problem, and should be worth less payment, then, the second point in figure 8-4 is moved down without moving the first control point. Following the formula, or from figure 8-4, it is interesting that the maximum pay factor will increase accordingly. This may not be what the highway agency wants. If the highway agency wants to control the possible maximum

pay factor, in addition to the original two control points, the linear equation is deficient for managing these three control points.

To solve the problem and force the pay schedule function curve to go through the three control points, including Maximum, AQL, and RQL pay factors, a second degree polynomial function is necessary. To illustrate the idea, let the x axis stand for the percent of defective (PD), and the y axis stand for the pay factor (PF). Both these two parameters are in terms of percentage, but in scales of decimal. The general form for a second degree polynomial function can be:

$$\mathbf{Y = a\ X^2 + b\ X + c}$$

To determine the three coefficients "a," "b," and "c," a system equation should be used. The following numerical examples are used to show the computing procedures.

Assume the highway agency chooses the following percentages:

1). The maximum pay factor is 105% based on the full bid price.

2). The PF for quality of AQL (PD=10%) is 100%.

3). The PF for quality of RQL (PD=40) is 70%.

That is,

when X1 = 0% , then Y1 = 105%

when X2 = 10% , then Y2 = 100%

when X3 = 40% , then Y3 = 70%

the system equation becomes (Refer to Figure 8-5):

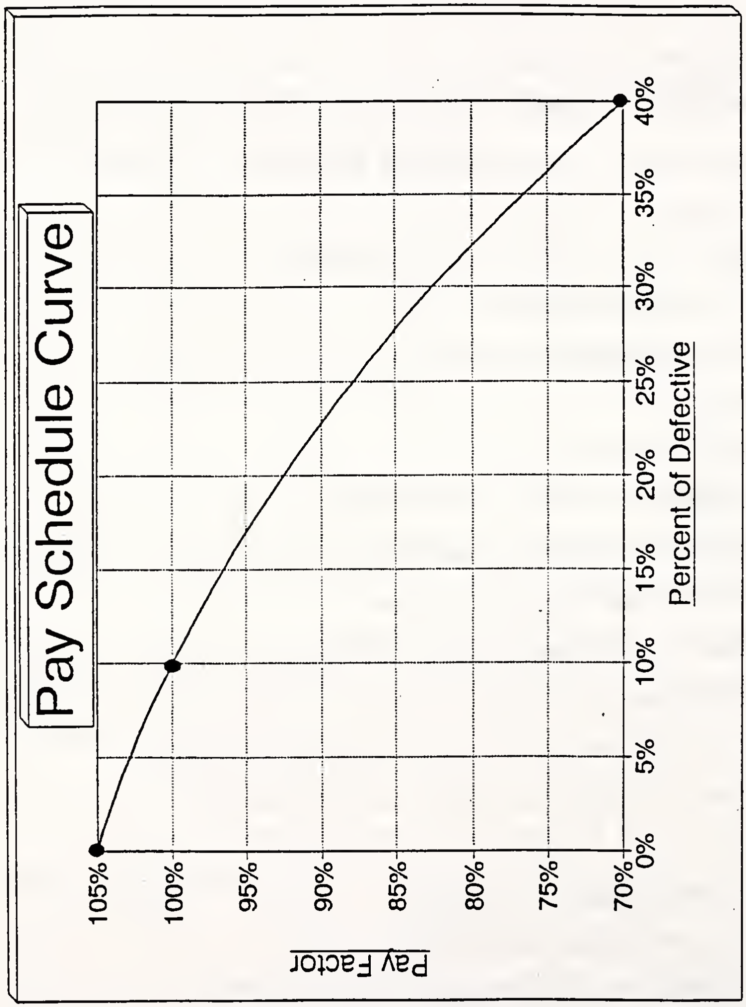


Figure 8-5: Second Degree Adjustable Pay Schedule Polynomial Curve

$$\begin{bmatrix} Y1 = a\ X1^2 + b\ X1 + c \\ Y2 = a\ X2^2 + b\ X2 + c \\ Y3 = a\ X3^2 + b\ X3 + c \end{bmatrix}$$

$$\begin{bmatrix} 1.05 = a * 0.0^2 + b * 0 + c \\ 1.00 = a * 0.1^2 + b * 10 + c \\ 0.70 = a * 0.4^2 + b * 40 + c \end{bmatrix}$$

Then a, b, c obtained are

a= -1.25

b= -0.375

c= 1.05

The pay factor function becomes :

$$\mathbf{PF = a * (PD)^2 + b\ (PD) + c}$$

$$\mathbf{PF = -1.25 * (PD)^2 - 0.375 * (PD) + 1.05}$$

Assume that the PD obtained from the field is 0.12 (or 12%). By inserting the PD into the previous equation,

$$\mathbf{PF = -1.25 * (0.12)^2 - 0.375 * (0.12) + 1.05}$$

then, $\mathbf{PF = 0.987 = 98.7\%}$.

After the percent of defective for a painting project is obtained, with this second degree pay factor function, the appropriate pay factor is obtained. For inspectors, the work involved is only plugging the PD into the derived pay factor function. With the power to control the desired three control points, a second degree function is recommended in the development of adjustable pay schedules.

8.4 The Application of Adjustable Pay Schedule

The previous chapter presents four acceptance sampling plans including: 1) Variable Single Sampling, 2) Attribute Double Sampling, 3) Variable Single Sampling without Risk Control, and 4) Attribute Proportion Single Sampling. All these sampling plans can be linked to the adjustable pay schedule through the parameter, percent of defect (PD) parameter. Regarding the application of adjustable pay schedules, the first and the third method are the same (variable); the second and the fourth one are the same (attribute). Thus, only the variable sampling and the attribute double sampling are explained. The following examples illustrate the application of the second degree adjustable pay schedule system in painting constructions.

Example

Assume the highway agency would like to control the following variables:

1). The maximum pay factor is 105% (based on the full bid price).

2). The Pay Factor (PF) for quality of AQL (PD=10%) is 100%.

3). The Pay Factor (PF) for quality of RQL (PD=40) is 70%.

As a result, the pay factor function, referred to section 8.3 is:

$$\mathbf{PF = -1.25 * (PD)^2 - 0.375 * (PD) + 1.05}$$

A steel bridge painting project with the bid price of $500,000 is applied to the adjustable pay schedule. The required total paint film thickness is 5.5 mils (current INDOT specification). Assume, in the sampling stage, the bridge is divided into 4 lots having the

sample size of 10 for each lot.

For Variable Sampling:

For Variable Single Sampling, assuming that the required sample size is 10 for each lot, the collected data could be similar to that found in Table 8-2.

Lot No.	Sample Size	Mean of Reading (μ)	Standard Deviation (SD)	Limit (L)	Quality Index $\frac{\mu - L}{SD}$	Percent of Defective
1	10	6.8	1.1	5.5	1.18	11.68%
2	10	6.4	0.9	5.5	1.00	15.97%
3	10	7.1	1.2	5.5	1.33	8.66%
4	10	6.7	1.0	5.5	1.20	11.24%
Average Percent of Defective is =						11.88%

Table 8-2: Pay Factor Example for Variable Sampling

The pay factor for this project can be obtained by the pay factor function, where the percent of defective is obtained by checking the Quality Index Table.

By

$$PF = -1.25 * (PD)^2 - 0.375 * (PD) + 1.05$$

Given that the PD is 11.88% (=0.1188), the adjusted pay factor is:

$$PF = -1.25 * (0.1188)^2 - 0.375 * (0.1188) + 1.05$$

then, $PF = 0.9878 = 98.78\%$

Applying the pay factor to the bid price of $500,000, the payment

for the contractor is:

$500,000 x 98.78% = $493,904.10

For Variable Single Sampling without the Risk Control method, the procedure for the adjustable pay schedule is the same as above.

<u>For Attribute Sampling:</u>

For Attribute Double Sampling, assuming that the decision parameters are:

First sample size $n1 = 10$

Second sample size $n2 = 10$

First acceptable number $c1=1$

First rejectable number $r1 = 3$

Second acceptable number $c2 = 4$

$x1$: the number of nonconforming items found in first sampling

$x2$: the number of nonconforming items found in second sampling

The data collected can be shown in Table 8-3.

Lot No.	n1	x1	n2	x2	n1+n2	x1+x2	Percent of Defective $\frac{x1+x2}{n1+n2}$
1	10	0			10	0	0%
2	10	1			10	1	10.00%
3	10	2	10	1	20	3	15.00%
4	10	2	10	2	20	4	20.00%
Average Percent of Defective (PD) is							11.25%

Table 8-3: Pay Factor Example for Attribute Sampling

The pay factor for this project can be obtained by the pay factor function:

$PF = -1.25 * (PD)^2 - 0.375 * (PD) + 1.05$

Knowing the PD is 11.25% (=0.1125), the adjusted pay factor is

$PF = -1.25 * (0.1125)^2 - 0.375 * (0.1125) + 1.05$

then,

$PF = 0.9919 = 99.19\%$

Applying the pay factor to the bid price of $500,000, the payment for the contractor is:

$500,000 x 99.19% = $495,996.09

For the Attribute Proportion Sampling method, the procedure for the adjustable pay schedule is the same as above.

4. Potential Problems in Using Adjustable Pay Schedule

In applying adjustable pay schedules, the following potential problems would probably be encountered:

1). The estimated percent of defective may be unreliable. The contractors may criticize the confidence of the data if random sampling is not performed well.

2). The derived adjustable pay schedule function may be too strict for the contractors. Because the adjustable pay schedules are usually only determined by highway agencies, they tend to favor the agencies. If this is the case, the contractors may try to compensate for what they perceive as an adverse

condition by raising the average bid price.

3). The agencies are usually reluctant to use an incentive payment. One problem may be the difficulty in raising the budget for the bonus payments. Also, the amount of the bonus or the penalty cannot be decided in advance. The additional value of the products received may not be proportional to the additional cost (Riley, Orrin 1991).

Because of the above concerns, before totally adopting the adjustable pay schedule system, two compromising approaches may increase the acceptability of the system.

1). The pay factor function can only be enforced on partial payment. For instance, during the trial phase, the highway agency may only apply 20% of the bid price to the adjustable pay schedule. The remaining 80% of the payment still uses the traditional pay schedule. As a result, the impact to the contractors can be reduced. This will make the system more acceptable. The pay schedule still keeps the function of motivating the contractors to maintain quality. Once the pay schedule system and the definition of quality level gain more trust, the percentage of the payment which is applied to the pay factor function could be increased accordingly.

2). Highway agencies should allow the contractors to choose between rework or receiving a reduced payment when their products are proved to be of poor quality. In case the contractors do not feel they have been treated fairly by being paid a reduced price, they can choose to remove the original work and apply the painting again. This rework should be inspected by the agencies. Regarding the DFT, close investigation should be taken. If the contractors just apply additional paint material on the original deficient paint thickness, the binding strength may be inadequate to tie the two layers of paint together.

8.5 Conclusion

By applying any one of the proposed acceptance plans presented in previous sections, the percent of defective (PD) of a specific painting construction can be obtained. Once the PD is available, the adjustable pay factor can be computed with the second degree polynomial pay factor function.

The need for an adjustable pay schedule is obvious. The contractors will be alerted and motivated. Thus, the quality of steel bridge painting can be better assured. In the long term, the benefits to both the owner and contractor are promising.

Chapter 9

Revision of Specification

9.1 Key Revisions to Standard Specification and Its Justification

A copy of the suggested revision to INDOT's bridge painting specification can be found in Appendix 9-1. The revised specification is roughly divided into two main sections: Materials and Construction Requirements. Materials are further described in another section of the Standard Specifications. Detailed specification of materials was beyond the scope of this research.

The construction requirement section is broken down into **General Requirements, Shop Painting and Field Painting** because of the differences in the way new bridges and old bridges are painted. The field painting section is divided into New Construction and Cleaning and Painting of Old Steel Bridges. The specification is concluded with a section on Payment, where the Statistical Acceptance Plan is described in Chapter 7, and the corresponding proposed inspection checklist is outlined in Chapter 11.

The focus of this revision to Section 619 of INDOT's Standard Specifications for painting steel bridges is on application, as opposed to materials per the original proposal. There are, however, three new paints which are suggested for review by INDOT which were

listed in the IDOT specification. The researchers recommend that INDOT continue their own search for paints and paint systems which not only meet technical requirements, but also environmental criteria.

One very recent and excellent source of test data on painting is the Performance of Alternative Coatings in the Environment study which was done by the Steel Structures Painting Council in cooperation with the FHWA and several state highway departments (Performance.., 1990).

Rather than discuss every revision, it is best to focus on some key quality parameters. Early on in this research effort, there were several quality parameters that were identified as being items which can have some or a great effect on the quality of the paint job. These parameters are listed in the following Tables which compare this suggested revision with the 1988 INDOT Standard Specification. The reasons for these revisions are discussed below.

The researchers found it extremely difficult to find a consensus about some of the quality parameters among various organizations. This is primarily due to the customization of paint specifications by each organization for their industry and/or geography (Appleman, 1988).

The paint industry is in considerable flux due to

environmental concerns that have arisen in recent years. Because of these environmental concerns, more and more new and high technology paints are being developed that require various kinds of preparation. The paint industry is in the midst of an era of great change and it is envisioned that this specification will be a continually changing and improving one. The increasing complexity in the painting industry is making it more and more difficult to write quality specifications that are generic and not ambiguous.

9.2 Comparison of Suggested New Specification with 1988 Version

QUALITY PARAMETERS	SUGGESTED REVISION	INDOT '88 VERSION
619.02 PAINT MATERIALS		
UNIT WEIGHT	W/IN 1% MANUFACTURER VALUE	NA
COMPATIBILITY OF COATS	ALL COATS FROM SAME MANUF.	????
CERTIFICATION	YES, BY MANUFACTURER SUBMIT @ PRECONSTRUCT. CONF.	NA
PACKAGING/LABELING	MANUFACTURER, BRAND NAME, LOT#, MANU. DATE, SHELF LIFE TO JOB IN ORIG. CONT. W/ LABEL	NA
STORAGE TEMPERATURE	>40F AND PER MANUF.	
619.03(a) SURFACE PREPARATION		
WASH	PRIOR TO SOLVENT CLEAN	NA
SOLVENT CLEANING	SSPC SP1	NA
PAINT/RUST/MILL SCALE REMOVAL	FIVE METHODS: FROM COMPLETE PAINT REMOVAL TO SPOT REMOVAL SSPC SP2,SP6,SP7,SP10 REFERENCED SURFACE VISUAL STANDARD - SSPC Vis 1-89 NO MORE THAN 2 WKS AFTER WASH	BLAST CLEANED > TWO THIRDS OF EACH SQUARE INCH RESIDUE FREE (EQUAL TO SSPC SP 6)
ABRASIVE pH	pH 6 - 8	NA
DEBRIS CLEANING	VACUUM OR DOUBLE BLOWING	NA
ANCHOR PROFILE	RECOMMENDED BELOW FOR EACH SYSTEM	NA

619.03(b) PAINT APPLICATION

MANUFACTURER'S INSTRUCT.	SUPPLIED <= PRECONSTRUCT. CONF.	NA
MIXING	MECHANICAL POWER,CONTINUOUS WHILE PAINTING FOR ZINC STRAINED <30 MESH	THOROUGHLY STRAINED <30 MESH
THINNING	PER MANUF. REC., OK'D BY ENGR NO THINNING OF ALKYD	PER MANUF. REC.
POT LIFE	NOT LEFT OVERNIGHT,PER MANUF.	NA
APPLICATION METHOD	SPRAY,ROLLER OR BRUSH	SPRAY,ROLLER OR BRUSH
TIME AFTER BLAST	APPLY PRIMER SAME DAY	APPLY PRIMER SAME DAY
DRYING & CURING	MEK RUB TEST BEFORE NEXT COAT FOR ZINC	SUFFICIENT TIME
TIME BETWEEN PRIME & FINISH COATS	PER MANUF,AVOID IRREGULARITIES	NA
MARKING	NO ERECTION MARKS ON BARE STEEL PAINT DATE	ONLY ERECTION MARKS PAINT DATE
PAINT SYSTEMS		
(EXISTING SYSTEMS SHOULD BE REVIEWED FOR ENVIRONMENTAL COMPATIBILITY)	PAINT SYSTEM NO. 1 PAINT SYSTEM NO. 2, PLUS TWO NEW SYSTEMS, MODIFY ONE ZINC SILICATE & VINYL (MODIFIED) ALUMINUM EPOXY & VINYL LEAD & CHROMATE FREE ALKYD	PAINT SYSTEM NO. 1 PAINT SYSTEM NO. 2
PAINT SYSTEM NO. 1 (EXIST.)		
ZINC SILICATE/VINYL	SINGLE PKG OR TWO COMP.	SINGLE PKG OR TWO COMP.
PROFILE	1 - 2.5 MILS,SP6-FIELD,SP10-SHOP	NA
DRY FILM - PRIMER	>= 2.5 MILS	>= 2.5 MILS
DRY FILM - 2ND/TOP COAT	>= 3 MILS	>= 3 MILS
DRY FILM - 3RD (EXT. ONLY)	>=2.5 MILS, TOT. >=8 MILS	>=2.5 MILS, TOT. >=8 MILS

PAINT SYSTEM NO. 2 (EXIST.)			
LEAD CHROMATE			
PROFILE	1 - 2.5 MILS, SP6		NA
DRY FILM - PRIMER	<= 2 MILS	<= 2 MILS	
DRY FILM - 2ND COAT	<=3.2 MILS	<=3.2 MILS	
DRY FILM - 3RD COAT	<= 3 MILS	<= 3 MILS	
PAINT SYSTEM NO.3 (IDOT)			
LEAD & CHROMATE FREE ALKYD			NA
PROFILE	1 - 3 MILS, SP# VARIES W/ CLEAN-ING METHOD		
DRY FILM - PRIMER	AVG. >= 2 MILS, <= 3 MILS		
WET FILM - 2ND/3RD COATS	AVG. >= 3 MILS,<= 4.5 MILS		
PAINT SYSTEM NO.4 (IDOT)			NA
ZINC SILICATE/VINYL HIGH BUILD/VINYL ENAMEL			
PROFILE	1 - 2.5 MILS		
DRY FILM - PRIMER	>= 3 MILS, <= 6 MILS		
DRY FILM - 2ND/TOP COAT	TOTAL AVG. >= 6 MILS		
DRY FILM - 3RD (EXT. ONLY)	TOTAL AVG. >=7 MILS		
PAINT SYSTEM NO.5 (IDOT)			
ALUMINUM EPOXY & VINYL			NA
DRY FILM - PRIMER	AVG. >= 6 MILS, <= 10 MILS		
DRY FILM - 2ND/TOP COAT	TOT. AVG. >= 9 MILS,<= 15 MILS		
DRY FILM - 3RD (EXT. ONLY)	TOTAL AVG. >=10 MILS		
<u>619.03(c) INSPECTION</u>	STATISTICAL TESTING BY LOT	RANDOM	
PLAN	SUBMIT < PRECONSTRUCT. CONF.		NA
FACILITIES	CONTRACTOR PROVIDE FOR INSP.		NA
DRY FILM MEASUREMENT	SSPC-PA2		NA
PROFILE MEASUREMENT	PROFILE DEPTH TAPE		NA

619.03(d) WEATHER		
TEMPERATURE (AIR & STEEL)	AIR MIN 40F MAX 100F STEEL MIN 50F MAX 130F	AIR MIN 40F
DEW POINT (DP)	SURF. TEMP. >= 5F OVER AIR DP	NA
RELATIVE HUMIDITY	<85%, 50 TO 85% FOR ZINC	MISTY
WIND VELOCITY	<= 15 MPH	NA
619.03(e) EQUIPMENT	CLEAN AIR TEST - ASTM D4285 MIN 100 PSI AND 250 CFM PER SSPC VOL 1, CH 2.4, TABLE 1	
619.03(f) TRAFFIC	MAINTAIN W/ MIN. INTERFERENCE	MAINTAIN W/ MIN. INTERFERENCE
619.03(g) PROSECUTION OF WORK	SUBMIT WORK PLAN @ PRECONSTRUCT. CONFERENCE	NA
619.04 SHOP PAINTING	MIST COAT ON TOP FLANGE	NA
619.05 FIELD PAINTING		
DATES ALLOWABLE	APRIL 1 TO NOVEMBER 15	APRIL 1 TO NOVEMBER 15
619.06 PAYMENT	LUMP SUM/UNIT PRICE	LUMP SUM/UNIT PRICE
METHOD OF MEASUREMENT	STATISTICAL TESTING BY LOT	NA

MISC. COATING PROBLEMS

RUNS & SAGS	BRUSHED OUT IMMEDIATELY	NA
MUDCRACKING	REMOVE	REMOVE
DRY SPRAY	REMOVE	NO OVERSPRAY
POROSITY	FREE OF PORES	NA

9.3 Key Revisions

The following is a step by step discussion of the key revisions in the proposed specification including reasons for the changes.

Paint Materials

Section 619.02 - Paint Materials

Although the selection/recommendation of paint is outside the scope of this project, there are other aspects related to materials that this specification must cover in order to assure their quality after they leave the manufacturer.

Unit Weight

The **unit weight** of the paint at the job site should be within 1% of the manufacturer's specified value for paints that prohibit thinning. This is to assure that there is a proper mixture of components and that no unauthorized thinning has been done (Flannigan, 1989). In the interview with Mr. Flannigan, an engineer in charge of painting construction for IDOT said that IDOT's Materials Testing Division had verified that this was a good, reasonable and relatively easy-to-test criteria for Alkyd paints. They use a scale and tare cup, which is provided in the resident engineer kits.

Compatibility

Compatibility is the ability of two different types of

coatings to combine or adhere to each other (Pinney, 1990). The compatibility of the paints which make up the multiple coat paint system is assured by requiring that they all come from the same manufacturer. This places the responsibility with the expert for putting the right primer with the right top coat(s).

Certification

Certification of the paint is required in order to show that the batch to be used has undergone QC testing and meets the manufacturers requirements. This insures that the batch will not be defective of paint. The certification, which is the manufacturer's seal of approval, becomes documentation for various things, including warranty on the paint. In one sense, the certification from the paint manufacturer represents what the QA specification is trying to eventually accomplish with the paint application contractor. The QC is done by the producers (not the buyers) and they take responsibility for the end result.

Packaging/labeling

The paint should arrive at the job-site with its original **packaging/labeling** so that it is clear that the right material has been brought and that it is not beyond its **shelf life**. The shelf life of the paint should be checked to insure that it is within its usable time period. Paints stored beyond this

manufacturer recommended period are likely to have undergone undesirable changes such as color and liquid separation, formation of lumps, hard pigment settling, changes in viscosity or pH, and gelling (Pinney, 1990). In addition, the paint data sheets, material safety data sheets and manufacturers' instructions should be supplied so that those on the job have a ready reference to answer questions related to thinning, application, and so forth. These items should also be kept on file for the specific bridge for future reference.

Storage temperature

The paint should be **stored** within the range of **temperatures** specified by the manufacturer; otherwise detrimental changes to the coating may occur.

> "For example, water based materials will spoil and become unusable at temperatures below freezing. Solvent based materials may utilize solvents which evaporate at high temperatures. High storage temperatures may also cause gelling in solvent based coatings. Deviations from recommended storage temperature ranges often cause drastic changes in the coating viscosity and shelf life." (Pinney, 1990)

Surface Preparation

Section 619.03(a) - Surface Preparation. Good surface preparation has always been critical to getting a good paint job.

> "Most premature coating failure can be attributed to inadequate surface preparation or lack of adhesion. The primary functions of surface preparation are: to clean

the surface of material that will induce premature failure of the coating system and to provide a surface that can be easily wetted for good coating adhesion." (Good Painting Practice, 1989.)

Washing

The first requirement for surface preparation is **washing** which entails removing all debris from the surfaces to be painted. This is done prior to solvent cleaning in order to remove the general and bulk debris and surface salts so as to reveal the special areas which require solvent to clean (Appleman, 1988). Blast cleaning alone may not remove salts and grease, which will detract from the adhesion of the paint (Good Painting Practice, 1989).

Solvent clean

The next step in the process is to **solvent clean** areas where the contaminants can not be removed by simple washing.

"Solvent cleaning is an essential process for two reasons: 1) Coating will not adhere to a surface containing oil or grease residue and 2) abrasive blasting and power tool cleaning can force deposits of oil and grease into the surface of the metal instead of removing it" (Pinney, 1990).

SSPC-SP 1 specification is an industry standard and referenced to provide reasonable, well documented guidelines. Aliphatic mineral spirits are required in the proposed specification because of the potential harm to personnel and environment from other kinds of volatile solvents.

Paint/rust/mill scale removal

Five methods (A through E) are specified to provide clear instructions for various kinds of **paint/rust/mill scale removal** (complete, partial, spot-heavy, spot-light, new steel). This is done because one method (as previously specified) is really not adequate to cover a variety of situations, and specifying several techniques is recommended in the reference by Appleman (Appleman, 1988). This flexibility will allow the INDOT engineers to customize the paint program for any given bridge to get the best and most economical solution. Some bridges may only require spot painting whereas others may need complete or partial paint removal. This revised document provides some guidelines for this. The appropriate method(s) for a given bridge must be specified in future contracts which reference back to this standard specification. These methods are patterned somewhat after the very well thought out SSPC specifications embedded in them (Method A - SP 6, Method B - SP 7, Method C - SP 6 for spots, Method D - SP 2, Method E - SP 10). Hand tool cleaning (SP 2) can be specified under the following conditions: 1) when the existing coating is in fairly good condition with only a few degraded areas, 2) when cleaning areas which are inaccessible to abrasive blasting, 3) where sand blasting can not be tolerated. If power tools are allowed, the surface must be checked for grease/oil contamination. (Pinney, 1990). Cost, the coating system to be applied, and the condition of the

metal determine the degree of blast cleaning required. Brush Off Blast Cleaning (SP 7) results are the least demanding and leave tightly bonded mill scale, sound rust and previous coatings. Commercial Blast Cleaning (SP 6) is essentially what is in the existing INDOT Standard Specifications and is next most demanding. It requires that two-thirds of each square inch (66.6%) be free of all visible residue. Near White Blast Cleaning (SP 10) is the most demanding requirement in this specification and requires that 95% of each square inch be free of all visible residue. Paint manufacturers will specify the level of cleaning required for a given system and application (spot versus complete paint). SSPC - SP 10 (near white blast) is specified for shop painting because it achieves the best results and is not hard to obtain in a controlled environment (Good Painting Practice, 1989).

An evaluation of the safety of the various abrasives was not done, but is an area which is recommended for future review and action. Some abrasives produce dust which may be harmful to people. Another area to investigate is vacuum blasting for recovery of harmful paint debris. Some vacuum systems can separate the paint debris from the abrasive, allowing its reuse plus greatly minimizing the hazardous waste (such as lead) that must be dealt with.

pH of the abrasive

The **pH of the abrasive** has been limited to between 6 and 8 because acidity/alkalinity will affect the adhesion of the paint as well as cause faster rusting (Good Painting Practice, 1989, Vol. 2, p. 22).

Debris cleaning

After the paint/rust/mill scale removal, the **debris cleaning** must be done to remove all loose matter from the steel. The vacuum and double blowing techniques are taken from the IDOT specification (Flannigan, 1989). Although this may seem an obvious step, the vacuum method is specified for merits briefly discussed above and the double blowing technique is specified to insure a thorough removal of debris which a single pass would generally not produce.

Anchor profile

The **anchor profile** is the end result of surface preparation, but the requirements are listed with each paint system because they are customized based on the specified primer thickness. The profile must be enough to provide good adhesion but not so much that peaks are not covered by the primer (Good Painting Practice, 1989). In general, it appears that new high-tech, environmentally friendly coatings will have more customized requirements, especially for profile and dry film thickness. It is difficult, if not impossible, to write a single set of

requirements to cover such customized parameters for a variety of new paints. As such, **it is recommended that painting specifications be written in modules so that paint systems, along with their critical parameters, can be changed in and out without a major overhaul to the document.** An effort has been made to move in this direction for this specification; therefore, paint systems and the parameters that are critical and specific to them are in their own section.

SSPC's visual standard 1-89 for anchor profile is specified for two main reasons: 1) to match the SSPC surface preparation requirements given in the cleaning methods and 2) because they provide a very good pictorial standard for use in the field.

In this initial specification revision, a test section for cleaning is required to allow INDOT inspectors to help guide the contractors and to show the contractors that INDOT is serious about getting quality paint jobs. In a true end result specification, this would not be present and should ultimately be phased out.

Painting

619.03(b) Painting.

Manufacturer's written instructions

The paint **manufacturer's written instructions** and product data sheets are referenced here to complement these specifications.

The application instructions provide recommendations for application techniques that will be good under normal conditions. Instructions for some items, such as mixing and drying times, must be considered mandatory. Other instructions, such as application equipment sizing, are suggested and vary with actual application conditions (Pinney, 1990). These are required to be supplied to INDOT at or before the preconstruction conference so that the inspector/engineer can review them prior to the job. In fact, one could argue that the ultimate end result specification might be as simple as: 1) specify paint system required and the number of coats, 2) instruct the contractor to "apply paint per manufacturer's specifications" and 3) insist on a warranty for the materials.

Mixing

The requirement for power **mixing** is taken from IDOT (Flannigan, 1989). It makes sense that power-mixing would be more thorough and less subject to variation than hand mixing. Power mixing is also required because it is best for multiple component materials such as zinc rich primers, epoxies and urethanes (Pinney, 1990). Continuous mixing is required for zinc-silicate because this is a typical manufacturer's requirement. Paints are required to be strained after mixing in order to remove any solid particles which may clog spray tips.

Thinning

Only thinner/**thinning** recommended by the manufacturer is allowed. The addition of thinner changes the application characteristics (primarily the viscosity) of the coating. Use of the wrong thinner can change the protective and application characteristics detrimentally and result in system failure. The addition of excess thinner reduces the achievable film build by lowering the sag point of the materials (Pinney, 1990).

Pot life

Paint should not remain in spray pots (**Pot life**), or other temporary containers overnight because it may form a skin or harden (Good Painting Practice, 1989, Vol. 2, p. 359).

Drying/curing and time between coats

As far as **drying/curing** and **time between coats** (recoatability), the new specification really only varies for zinc-silicate where it requires an MEK rub test prior to applying the vinyl. This comes from the IDOT specification and is meant to provide a physical test other than curing time, which can be affected by humidity and temperature (Flannigan, 1989). The proposed specification references the manufacturer's instructions regarding recoatability for any paint, which brings a more objective requirement than the current specification of "sufficient time" (Good Painting

Practice, 1989). Drying and curing times change with temperature variation and additional data may be required from the manufacturer concerning times for lower and higher temperatures other than that given on the paint label. Premature or late application of additional coats can cause numerous problems such as improper surface curing, poor adhesion or cohesion and uncured coatings. (Pinney, 1990).

Application methods

Allowable **application methods** (brush, spray or roller) are discussed, but this is really more recipe oriented and should probably be phased out or taken out completely. Its origin is SSPC PA 1 sections 7.3.4, 7.3.5, 7.4.3 and 7.5.2.

Paint systems

Section 619.03(b) - Paint Systems. Two of the suggested new paint systems (Aluminum Epoxy with Vinyl, and Lead and Chromate free Alkyd) are taken from IDOT's revised specification and are intended to be more environmentally compatible in replacing paints containing lead or chromates. The researchers do not have personal knowledge to recommend them, but have listed them for INDOT's review and to show what is being used by a neighboring state. The aluminum epoxy system has been marketed as having the ability to encapsulate lead paint, therefore doing away with the requirement for removing it and handling it as a hazardous waste. However, Illinois reports that this

has not been greatly successful due to the epoxy's poor adhesion to the existing paint (Flannigan, 1991). Proposed paint system #4 (IDOT's zinc silicate and vinyl system) is a slight modification to the existing INDOT system, using an organic zinc with vinyl. The proposed version provides better detail on application requirements and qualitative-quantitative parameters for eleven colors. The existing systems have been left for INDOT to review in light of the upcoming environmental regulations.

Anchor profile and dry film thickness (DFT)

The **anchor profile and DFT**'s specified for the new paint systems are taken from IDOT's revised specification and are based on IDOT's evaluation of various paint system specifications and manufacturer's recommendations (Flannigan, 1991). The general reasoning for the selection of optimal anchor profile characteristics was discussed previously. Concerning dry film thickness, generally speaking the primer DFT is designed to provide a good adhesive foundation for the succeeding coats and to be sacrificially corrosive in protecting the steel. It must also be thick enough to cover the peaks of the anchor profile to avoid pinpoint rusting. The intermediate coat may provide one or all of the following functions: 1) improve chemical resistance, 2) serve as an adhesion or tie coat between the primer and the top coat when they are not compatible and 3) increase the film thickness of

the coating system which is particularly critical on pitted steel where liquid coatings tend to flow away from sharp edges. The top coat may improve the chemical resistance of the system and provide characteristics such as color, gloss, mildew resistance and wear resistance (Pinney, 1990).

From the researchers' point of view, it seems certain DFT's have empirically evolved over time for a given paint as being optimal as related to material cost, labor cost, steel protection ability, and so forth. Tests have been done to corroborate such values and the Performance of Alternative Coatings in the Environment reference includes some of this data along with analysis (Performance.., 1990). The researchers recommend further review of this relatively new information for possible guidance in fine tuning the technical aspects of this specification.

For proposed paint system No. 4, the new specification requires SSPC-SP 10 (near white blast) cleaning as opposed to the standard SP 6. This comes from the IDOT specification; Illinois has chosen to go for the better cleaning because they believe it will pay off in the long run through longer lasting paint jobs (Flannigan, 1991). The zinc primer must perform better with a more thorough cleaning.

Inspection

Section 619.03(c) - Inspection. SSPC PA 2 is established as the reference for procedures for calibrating and using magnetic gauges to measure DFT. It was chosen because it is a well thought out and clear standard. However, this specification will introduce a statistical acceptance plan for determining adequate DFT overall coverage.

Inspection plan

The proposed specification requires that the contractor, in addition to providing access for inspection, must also submit a **plan** for such to INDOT at the preconstruction conference. This will allow the inspector to have input into whether he or she approves of the plan, since many inspectors have complained of unsafe practices which prevented them from checking all areas of a job. This unsafe access seems to have become some contractors' technique for getting away with substandard work in the hard-to-reach places of some bridges. A plan may also allow for resolution of questions concerning intent or interpretation prior to starting work when there is no pressure to keep the job moving (Pinney, 1990).

Weather conditions

619.03(d) - Weather conditions. The air temperature range of 40-100 degrees F comes from IDOT's specification (Flannigan, 1989). The lower end value (40 degrees F) comes from SSPC PA 1

section 6.1.

"Low application temperatures inhibit cure of most paints and in the case of two component epoxy, cure may never occur below 50 degrees F. Low temperatures also cause materials to thicken, which changes their application characteristics and slows solvent and thinner evaporation. High application temperatures cause solvents and thinners to evaporate too quickly which leads to dry spray pinholing, catering and mud cracking" (Pinney, 1990).

Surface temperature, dew point, relative humidity, wind speed

The requirement that the **steel surface temperature** should be 5 degrees F greater than the **dew point** comes from SSPC PA 1 section 6.2. and is essentially meant to prevent the painting of moist surfaces. The **relative humidity** is specified at less than 85%, except for zinc-silicate, where it should be 50-90%. This comes from the IDOT specification (Flannigan, 1989) and is based on review of paint manufacturers' requirements. Below 40% relative humidity, zinc rich primers may not harden sufficiently to accept top coats; if the humidity is above 80%, other coatings may not cure properly due to too much moisture (Pinney, 1990). The amount of moisture in the air is important for proper application and curing of paints (Good Painting Practice, 1989). Allowable temperature and relative humidity ranges should be established for each product and monitored closely for bridge work since conditions can vary greatly throughout the day. Finally the **wind speed** is specified to prevent the contractor from trying to work when

it is too windy, could cause dust contamination of the paint, improper curing due to quick loss of or unwanted paint blown onto the wrong surfaces.

Equipment

Section 619.03(e) - Equipment. There are some equipment requirements added to help present typical problems in this area. Gauges are required on equipment per SSPC-PA 1 section 7.3.1 because the manufacturers' instructions require certain pressures for good application and because it is safe. Valves are also a safety feature. The requirement for minimum 100 psi and 250 cfm comes from IDOT's specification and is based on their past experience (Flannigan, 1989). Pressures below 90 psi reduce productivity and may reduce the anchor pattern (Pinney, 1990). The requirement for filters, traps and separators comes from SSPC-PA 1 section 7.4.2 and its purpose is obvious. Testing for cleanliness of the equipment is suggested in SSPC-PA 1, section 7.3.3 and ASTM D4285 is a standard test for this. This is to prevent contamination of the surface from oil or grease from the equipment, which will cause delimitation of the paint and/or "fish eyes."

Chapter 10

Contractor Pre-certification

10.1 Background

The low-bid concept has been adopted by public works for 150 years. The bidding strategies are intended to provide the taxpayer with the benefits of the free market by delivering efficient products at the lowest price (Harp, Darrell, 1991). Price is important; however, it has become an increasing burden on necessary requirements such as service life cycle, finish time, and quality of the construction. The highway agencies often separate a new construction and its maintenance into distinct programs with separate funding. The lowest initial cost may not indicate the accomplishment of the lowest overall cost in the circumstances of a completed project.

As a result, the DOT may want to assure that the rewarded painting construction bidder not only potentially provides the lowest life cycle cost, but also is "capable and responsible" for finishing a quality work. To achieve this, the DOT could pre-certify all bidders. With this system, the contractors interested in preparing the bid would be asked to submit the credentials about expertise and capability of successfully complete the work. If DOT has doubts regarding the contractor's capability to finish a

quality work, the agencies can simply withhold the certification.

According to Jeffrey Russell, the obstacles for the owner in adopting the pre-certification program are (Russell, S. Jeffrey, 1988):

1) The high cost related with the developing and implementing of the contractor pre-certification process.
2) The difficulty of developing a consistent decision making process for objective decisions.

However, several benefits from the Contractor Certification Program have caused many agencies to adopt this program. In general, the advantages of contractor pre-certification are (Russell, S. Jeffrey, 1988):

For Owner:

1) More efficient application of contractors' resource can be utilized. Improvements in terms of time, cost, quality, and safety can be achieved.
2) The probability of contractor default and delay can be reduced. The risk of contractor failure can be minimized.
3) The time and money required to evaluate the bids can be minimized by reducing the number of eligible bidders.

For Contractors:

1) The rate of return can be increased by reducing the investment of extending resources on projects which the contracts are

less capable of preforming.

2) Uncertified contractors can be screened out, which may introduce unreality into the bidding process.

10.2 The Need for Painting Contractor Certification Program (PCCP)

Interviews with experts in the shops, fields, and DOT administration offices, indicated a need for pre-certification for painting construction. The findings are summarized as bellow:

1) Working with a lump sum contract system, DOT must inspect very carefully and closely to ensure the quality. Otherwise, DOT will run off the good contractors who are not counting on cutting corners to produce the lowest bid. A contractor certification program is necessary to signal out and eliminate bad-credited contractors who adopt a hit-and-run policy.

2) Membership in SSPC's certification program supplies a positive influence to offset the low bid mentality of low quality. Contractors become a part of a society group. This also provides a forum for contractors to discuss problems together, where previously they have no cause for interaction.

3) There are many parameters involved in defining painting quality. Because of this complexity, it is often very difficulty for an inspector to completely monitor the

application through the whole painting process. Therefore, the quality of DOT's inspections is not guaranteed, and the pre-certification program plays the role of safe-guard.

4). Since SSPC has already established the PCCP system, the obstacle of the aforementioned high-cost of developing a program is overcome. Contractors can thus be evaluated without any additional efforts by the highway agencies.

10.3 Current Practice of SSPC's PCCP

The SSPC's painting contractor certification program (PCCP) is a national pre-certification service developed for facility owners to certify a painting contractor's capability to produce quality surface preparation and coating application. The PCCP requires contractors to provide adequate personnel and to follow a set of procedures before certification can be awarded. The SSPC hires the consulting firm as the third-party to do the evaluation. After the contractors submit the information necessary for certification, the auditors arrange an on-site evaluation of the contractor's operation. They observe the progress, interview the company management and personnel, and report their final recommendation to the contractor. The SSPC then reviews the auditors' report and determines whether certification will be granted (JPCL, October, 1990, pp. 90-91).

Four areas of concerns in the certification process are: 1) management procedures, 2) technical capabilities, 3) quality control, and 4) safety. Among the above four areas, quality control is the major concern in the certification program. Two categories in the quality control portion are: 1) personnel certification, and 2) inspection procedures and recording systems (JPCL, October, 1990, p. 90). For the first category, supervisors and coating inspectors are evaluated. By examining the training and inspection programs available to inspectors and how often they are used, the quality control portion is evaluated. For the second category, inspection procedures and record-keeping methods are analyzed. How the contractor records and uses standard specification for inspection works is evaluated. Contractors are required to maintain a system for filling inspection reports. The workers who use inspection equipment must demonstrate their proficiency and knowledge of the procedure.

Up to October 20, 1991, there were 25 painting contractors certified by the PCCP (JPCL, December, 1991, pp.12-14). Several facility owners have required such certification as a pre-requirement for bidding, especially on difficult projects, such as those that require lead paint removal in sensitive areas (JPCL, November, 1991, p. 5). As an example, in April of 1990, the Illinois Department of Transportation announced its schedule for implementing PCCP. After August 31, 1990, PCCP certification will be requested for applying coating to all truss bridges. For all

projects exceeding $200,000, let after April 15, 1991, certification will be required. Certification will be required for every Illinois DOT painting project after April 15, 1992 (JPCL, April, 1990, p. 5). Some of the real cases requiring PCCP by facility owner in crucial structures are (JPCL, November, 1991, pp. 6-7):

- New Hampshire Department of Transportation on the Portsmouth Kittery Project involving a bridge over Piscataqua River.

- Tennessee Valley Authority, in maintenance contract about 41 hydro-fueled and fossil-fueled power plants.

- The Connecticut Department of transportation plans to use PCCP on a project-by-project basis, beginning in 1992.

Several other agencies plan to implement PCCP including Utah DOT, the New York State Thruway Authority, and Exxon Chemicals. Illinois DOT requires that their bidders should obtain the certification of SSPC's PCCP.

According to Illinois DOT's experiences, three advantages of utilizing an independent agency (SSPC) for certification were revealed (JPCL, January, 1990, pp. 48-49):

1) A professional organization can provide a thorough

investigation of painting contractors' certification.

2) Painting subcontractors can be certified independently by the main contractors.

3) DOT can insure certified contractors without direct involvement with the pre-certification process.

10.4 Conclusion

The application of contractor pre-certification is still in its initial stages and only 25 contractors obtained the certifications from SSPC's PCCP. Pre-certification of bidders restricts the entry of new firms into public works construction, and thus results in restricting the number of contractors available to the agency. This causes the bid price to raise a problem which has been already found in Illinois DOT's projects. However, in the near future, if more agencies support PCCP, more contractors will try to obtain the certification. More competition may bring down the bid price to more normal levels. The quality of the painted structures can be better assured by certified "responsible" and "capable" contractors.

Chapter 11

Implementable Inspection Procedure

11.1 Background

Among the four sampling methods developed in previous chapters, the variable sampling method is initially applied in developing inspection procedures. These procedures are formatted into a set of step-by-step checklists. They cover detailed inspection steps, supplying a precise guide to inspectors' daily practices. The checklists are divided into two major versions consisting of Shop and Field inspection checklists. For shop painting inspections, there are three stages including: 1) Pre-inspection Stage, 2) Surface Inspection Stage, and 3) Priming Stage. Field painting inspections consist of four stages including 1) Pre-inspection Stage, 2) Surface Inspection Stage, 3) Priming Stage, and 4) Top/Intermediate Coating Stage. The instructions for using the checklists are shown in Appendix 11-1, 11-4, 11-5 and 11-6. The checklists designed for Shop and Field painting inspection are attached in Appendix 11-2 and 11-3 respectively. A detailed example at the end of this chapter illustrates the use of the checklist forms.

11.2 Development Process

During the development of the inspection procedures, prototype

checklists adopting the variable single sampling method were introduced into both the shop and field. The uses and benefits of the checklists were explained to INDOT's inspectors. After the inspectors tried the checklists, feedback was retrieved to modify the checklist several times. The work loads imposed on the inspectors were sincerely considered. Any possible approach to reduce the inspectors' work load was taken in revising the checklists.

A serious problem was encountered during the testing stage. To apply the variable single sampling method, the computation of statistical parameters such as standard deviations is necessary. However, due to the limitation of inspectors' statistical background, the variable single sample plan was not executable. For this reason, an alternative, attribute double sampling method was initiated. The "attribute" "double" sampling method was adopted in the checklists because it has two advantages. First, the "attribute" provides the benefit of easy application. Second, the "double" can reduce the average sample size. Adopting this method can reduce the work load imposed on the inspectors, and make the sampling method more implementable.

11.3 Sampling Scheme for Lot

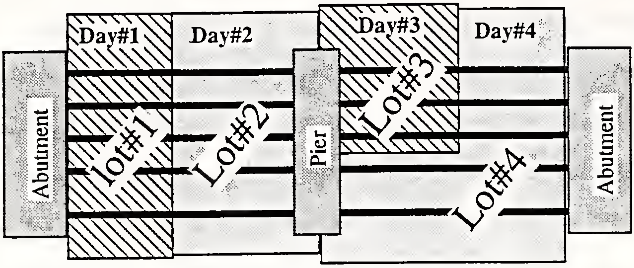
The basic unit for an acceptance scheme is designated as a "lot." The selection of lots in the checklist is as follows.

For Profile

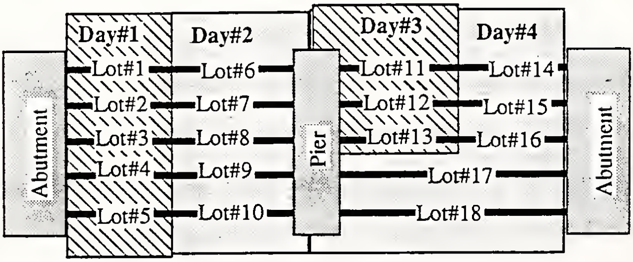
The daily product of blasting is treated as a lot (Figure 11-1). Within a lot, 10 profile measurements should be "randomly" taken for the first sampling. If the number of defect measurements is 0 or 1, the decision is made to accept the lot. If the number of defect measurements is 3, the decision is made to reject the lot. If the number of defect measurements is 2, a second sampling of 10 measurements is necessary. If the number of total defect measurements in the 20 measurements is less or equal to 4, the decision is made to accept the lot; otherwise, the lot is rejected.

For Primer or Top Coat

It is efficient to designate one beam as a lot. However, one beam may take several days to be painted. Within the same day, the quality of the painting is assumed to be homogeneous. Accordingly, the length of one beam member of one work day's product is treated as a lot. In other words, one beam may be stratified into several lots according to the number of working days taken to paint it. Assume, for example, that there are five beams in a steel bridge. The contractor finished the painting in two days. Each beam takes two days to be painted. With 5 beams multiplied by 2 days, the bridge is stratified into 10 lots. Figure 11-1 illustrates the layout of lot schemes. Within each lot, the attribute double sampling method is applied; the acceptance or rejection decisions are made for each lot.



Lot Scheme for Profile Sampling
(Daily Product)



Lot Scheme for Primer/Top-Coat Sampling
(One Beam of Daily Product)

Figure 11-1 : Layout for Setting Lot Schemes

Figure 11-1: Layout for Setting Lot Schemes

Coding System for Beam Numbers and Lot Numbers

A standardized coding system for beam number and lot numbers can facilitate the recording procedure. The proposed coding system for lots consists of two major parts including: 1) the number assigned to the beams, and 2) the date of painting. For example, "11-12-05" means that beam number is 11 and the date of painting is December 5th. In filed painting construction, usually a long beam is painted in several days. The code for date can be utilized to distinguish the date the lot was painted. It is suggested that the number of beams be coded from the North to South; or from the West to the East. If the directions of the beams are between South-North and West-East, the road above the bridge is adopted to approximate the direction. Figure 11-2 illustrates the coding system.

11.4 Final Results

A complete and implementable checklist was developed. To fulfill the proposed acceptance plan, this checklist served as the guidebook of inspectors' daily work plans. The checklist and its use instruction are shown in Appendix 11-1 to Appendix 11-6. Flow charts of the inspection process plans for shop and field painting are shown in Figure 11-3 and 11-4 respectively. The four quality assurance key questions including: 1) What do we want? 2) How do we order it? 3) How do we make sure that we get what we order? and 4) What do we do if we do not get what we ordered? All are answered in the checklist. With this checklist, the inspectors know where to inspect, how many measurements are necessary, and how to make

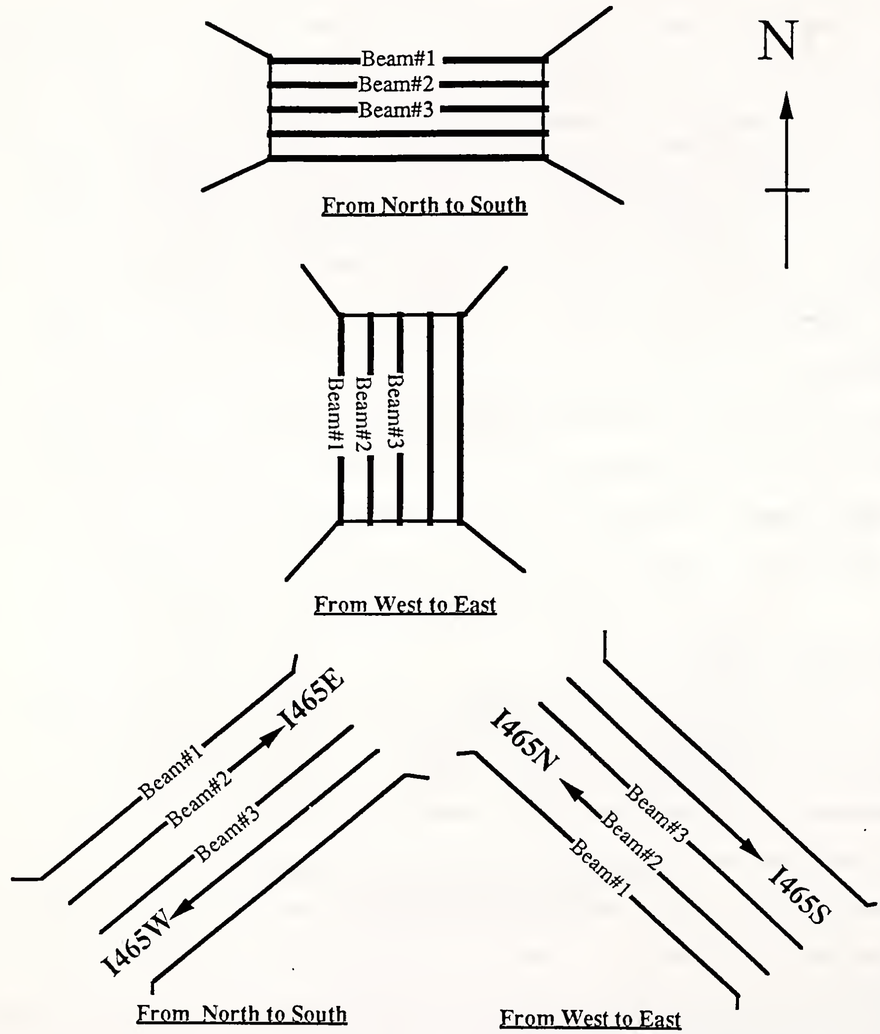


Figure 11-2: Coding System for Beam Number

Figure 11-2: Coding System for Beam Numbers

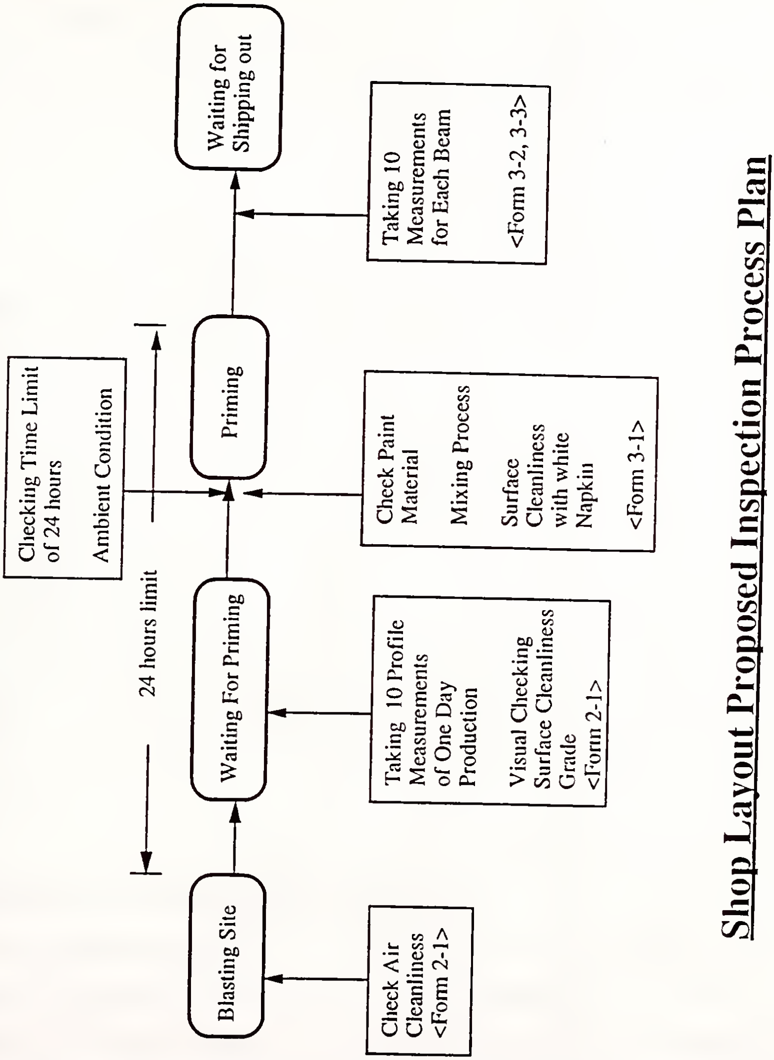


Figure 11-3: Shop Layout Proposed Inspection Process Plan

Figure 11-3: Inspection Plan for Shops

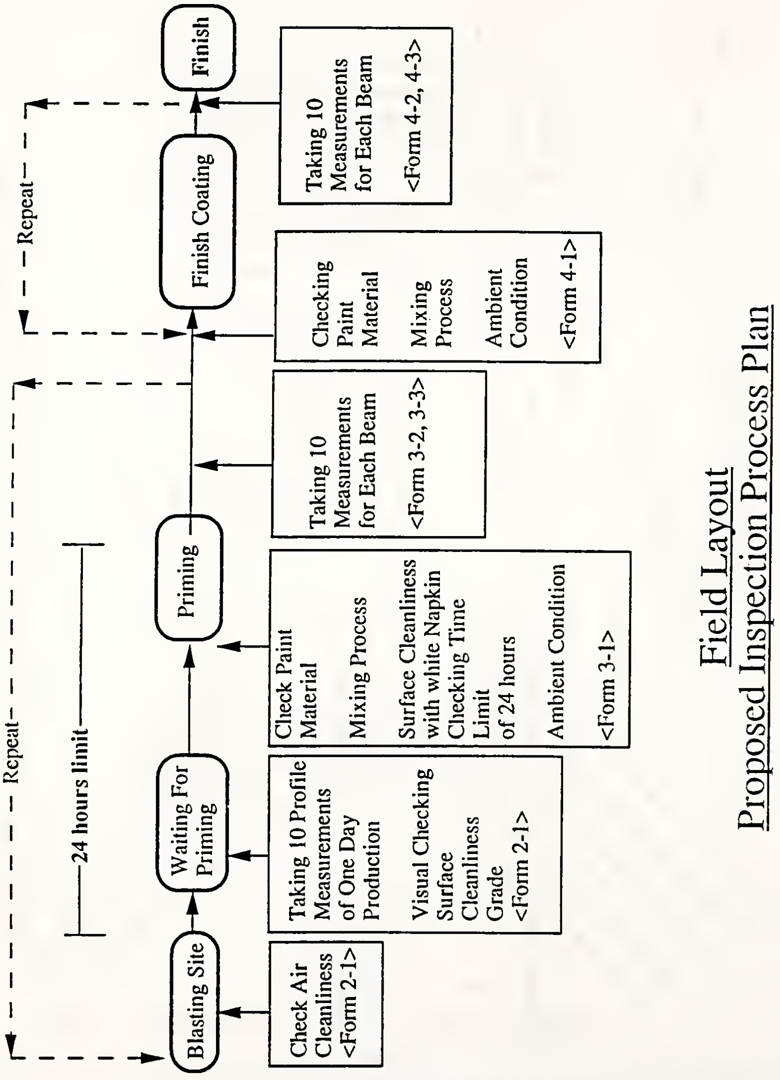


Figure 11-4: Field Layout Proposed Inspection Process Plan

Figure 11-4: Inspection Plan for Field Painting

acceptance/rejection decisions. However, the inspection system cannot automatically improve the quality by itself. In the contrary, the proposed inspection system and checklist are designed to help inspectors who want to do a good job, but have no system to follow.

In the proposed acceptance plan, the attribute double sampling method was adopted, with the decision parameters, $n1=n2=10$, $c1=1$, $r1=3$, and $c2=4$. If the product has the quality of 9% defective (AQL), it will be accepted with the probability of 95%. If the product has the quality of 42% defective (RQL), it will be accepted with the probability of only 5%. The owner's and producer's risk are both controlled at a 5% level. To set up the above parameters, the data collected from the fields were referred and analyzed. The DOTs may consider these settings over-strict or insecure. The final decision for these parameters is the privilege of highway agencies. However, the procedure for the acceptance plan system will be the same.

11.5 Example for Using the Checklists

As mentioned before, the inspection procedures for field bridge painting construction are divided into four stages including: 1) pre-inspection, 2) surface preparation inspection, 3) primer inspection, and 4) top-coat inspection (Figure 11-4). To illustrate the application of the proposed inspection system and checklists, the following simulated example is presented. The

filled-in checklists for the example are attached at the end of this chapter.

Example

Assume that on August 24, 1991, the steel bridge located at the overpass of Vermont Street and I-65 in Indianapolis, Indiana, was scheduled for painting. This steel bridge consists of eight I-shape beams structured in two spans. The configuration and beam number are shown in Figure 11-5. The engineer, Steven, from INDOT was taking charge of inspecting the quality of this painting project. The painting contractor, S.G. company, planned to finish the surface preparation and priming in two days (August 24, 25). Three days after priming, the contractor planned to apply the finish coat in one day (August 27). The application plan, information about traffic control, and the brand of the proposed paint material used were submitted to the Inspector Steven the day before application.

Meanwhile, Inspector Steven reviewed the contract and the application plan submitted by S.G. Company. He checked to make sure that the inspection equipment was ready to work. The checklist (Form 1-1) was then filled in according to the completeness of the preparation. If the answers to the questions in the checklist were yes, then "yes" are circled; if the answers were "no," the requirements must be satisfied before the painting can be started (Form 1-1). After all items on Form 1-1 are satisfied, Inspector

Steven informed the contractor to start the work according to the plan. At this point, the Stage-II (Surface Preparation) began.

In Stage-II, surface cleanliness, air supply cleanliness and profile were checked. The time of blasting (9:00 A.M., August 24, 1991) was recorded to make sure that the interval between blasting and priming was less then 24 hours. SP6 standard was required for surface cleanliness. The blasted surface was to have a profile between 1.5 to 3.5 mils. Based on the daily product, ten profile measurements (sample size) were first randomly taken from one day's product (August 24). The number of the defect items in the first sampling was 2. Following the algorithm of attribute double sampling, a second sample of 10 measurements was randomly taken from the same lot (Form 2-1). The defect number from the total 20 measurements was 4, signalling to the inspector that the profile passed the test. At the same time, the areas where profiles were measured were checked, and the surface cleanliness grades, such as SP6, were recorded. Those beams that did not reach the SP6 grades were scheduled to be reworked.

After each check item in the surface preparation was accepted, Stage-III started. The contractor, S.G. Company, planned to prime on the afternoon of August 24. The label and batch number of the paint material was checked. Inspector Steven also checked the blasted steel surface by white napkin to make sure the surface was free of abrasive, dust, or grease. However, when Inspector Steven

measured the ambient conditions, it was found that the steel surface temperature (55°F) was not higher than the dew point (53°F) by 5°F. Consequently, the priming was stopped right away. At 2:00 P.M. on the same day, the previous ambient constraint was satisfied and the priming was allowed to resume. The interval between blasting and priming was 6 hours, which fulfilled the criteria of being less than 24 hours (Form 3-1).

After finishing the priming, according to the specification, the contractor was asked to assist Inspector Steven to access the bridge for inspection. To record the inspection results, the lot numbers were coded by 1-8-24, 2-8-24, 3-8-24, and so forth. The first digit stands for the beam numbers from the North to the South, and the rest of the codes indicate the application date (August 24). One beam can be painted on different days. The length within one day's painting on one beam is treated as one lot (Figure 11-6). Within each lot the attribute double sampling plan is taken.

For beam #1 (1-8-24), all of the ten primer thickness measurements conformed with the requirement of a minimum of 2.5 mils, and the visual inspection also satisfactory. As a result, lot 1-8-24 was accepted. For lot 2-8-24, no measurement was under the limit of 2.5 mils. However, dry spray was found visually by Inspector Steven in lot 2-8-24. Even though the quantitative dry film thickness (DFT) measurements passed the test, this lot was rejected. Only after both the **DFT** and **Visual** Inspection

requirements are satisfied can the lot be accepted. That is, if either one of the two requirements, DFT or Visual Inspection, fails, then the lot fails. For lot 3-8-24, 3 measurements were out of the limits in the first sampling. No visual inspection was necessary and the lot was rejected. For lot 4-8-24, there were 2 defect readings in the first sampling requiring the second sampling. In total there were 3 defect readings in this lot which meant the lot was accepted. For lot 5-8-24, a 5 defect total reading made the lot rejectable. Likewise, the acceptance or rejection decisions were made lot-by-lot, which were filled in on Form 3-2. On August 25, the second half of the bridge was sand blasted and primed again. The lots were coded by 1-8-25, 2-8-25, 3-8-25, and so on. The inspection procedures were the same as those on August 24. For lot 6-8-25, the run was found; no DFT measurements were necessary before the lot was rejected. Form 3-3 is the summary for the detailed tables in Form 3-2. All the rejected lots were repaired at the request of Inspector Steven and the works was redone before the day of top coating.

Assuming that two days later, all the rejected primed beams were repaired and accepted, the contractor then informed Inspector Steven that top coating would begin on the morning of August 27. However, at the job site, because the wind speed was reported to be as high as 25 MPH, Steven halted the top coating before it even started. At 1:00 P.M. on the same day, the wind speed slowed down to 10 MPH; the contractor then got the permission to start the top

coating (Form 4-1). Of course, before the painting, the label and batch number of the paint material were checked. The mixture of the paint material was also monitored carefully by Steven.

After the top coating was finished and dried, the contractor assisted Steven to access the bridge. The top coating sampling plan was taken again. The procedure is similar to the primer sampling. Based on the sampling scheme, one beam of one day's product was a lot. At this time, however, the length of the whole beam was treated as a lot because the contractor finished all the top coating in one day. Again, the lots were coded by 1-8-27, 2-8-27, 3-8-27, and so on (Figure 11-7). The DFT and Visual inspection were taken lot by lot (Form 4-2). Inspector Steven then requested that the failed lots to be reworked. The summary of Form 4-2 was tabulated in Form 4-3.

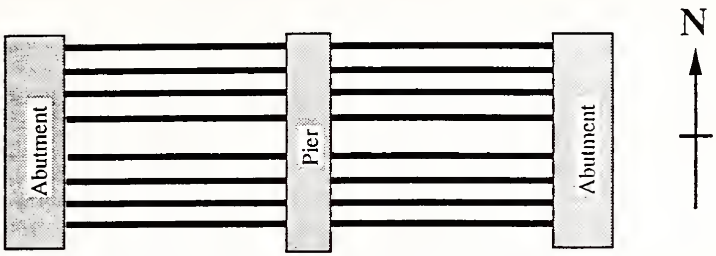


Figure 11-5 : Configurateion of the Example Bridge

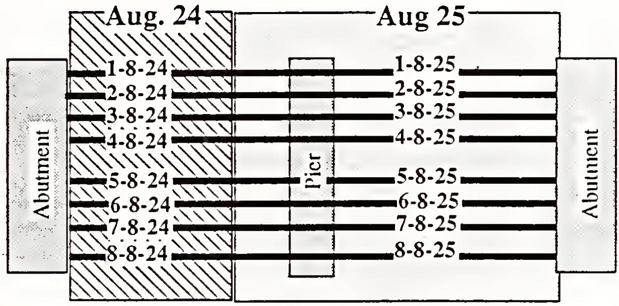


Figure 11-6 : Lot For Primer

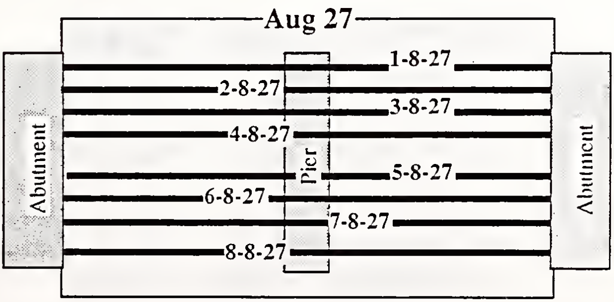


Figure 11-7: Lot For Top Coat

Figure 11-5, 11-6, 11-7:

Form 1-1

Stage-I (**PRE-INSPECTION FOR <u>FIELD</u> PAINTING**)

Date 8-24-1991

Inspected by Steven

District G.F. Structure # I-65

Contract # HPR-2029

Contractor or Sub. S.G

1. Has the contract of the project been reviewed? .... Yes No
2. Did the contractor submit the paint manufacture instructions? .... Yes No
3. Did the contractor submit the application plan/schedule? .... Yes No
4. Has the traffic control and accessing plan been discussed with contractors? .... Yes No
5. Is following equipment ready to be use?

Psychrometer	Yes	No
US Weather Bureau Psychometric Tables	Yes	No
Surface Temperature Thermometer	Yes	No
Dry Film Thickness Gauge	Yes	No
Testex Micrometer with X-coarse Tape	Yes	No
SSPC Surface preparation Specifications (SSPC 1-89)	Yes	No
NBS Calibration Standard	Yes	No
Tape Measure	Yes	No
Flash Light	Yes	No

Form 2-1-1

Stage-II (**SURFACE PREPARATION INSPECTION FOR FIELD PAINTING**)

Date 8-24-1991

Inspected by Steven

District G.F Structure # I-65

Contract # HRP-2029

Contractor or Sub. S.G.

Water Wash Cleaned. Yes No. Time/Date of Wash 8-24-1991

Solvent Cleaned ... Yes No. Air Cleanliness ... Yes No.

Required Profile: 1.5-3.5

Required Surface Cleanliness Grade: SP6

Daily Working Report for Profile Measurement

<<First Sampling>>

	Location Beam No.	Profile Reading (mils)	Time/Date of Sand Blast	Visual Cleanliness Checking SSPC Grade of Steel Surface
1	1-8-24	2.2	8/24 9:00am	SP6
2	1-8-24	2.0	"	SP10
3	2-8-24	2.3	"	"
4	2-8-24	1.8	"	SP6
5	2-8-24	1.4*	"	"
6	3-8-24	2.5	"	"
7	4-8-24	2.6	"	"
8	5-8-24	2.7	"	"
9	6-8-24	2.5	"	"
10	7-8-24	1.4*	"	"

Number of Defect (x1=): 2

If (x1≤1) then Accept

If (x1=2) Take Second Sampling *

If (x1≥3) Reject

<<Second Sampling>>

11	1-8-24	1.3*	8/24 9:00 pm	SP6
12	2-8-24	2.2	"	"
13	2-8-24	2.8	"	"
14	3-8-24	3.6*	"	SP10
15	2-8-24	3.2	"	SP6
16	3-8-24	3.0	"	"
17	4-8-24	3.1	"	"
18	5-8-24	2.8	"	"
19	8-8-24	2.7	"	"
20	8-8-24	2.8	"	"

Number of Defect (x2=): 2 Total Number of Defect (x1+x2=) 4

If (x1+x2 ≤ 4) then Accept *

If (x1+x2 > 4) Reject

Form 2-1- 2

Stage-II (**SURFACE PREPARATION INSPECTION FOR FIELD PAINTING**)

Date 8-25-1991

Inspected by Steven

District G.F. Structure # I-65

Contract # HRP-2029

Contractor or Sub. S.G.

Water Wash Cleaned. Yes No. Time/Date of Wash 8-25-1991

Solvent Cleaned ... Yes No. Air Cleanliness ... Yes No.

Required Profile: 1.5-3.5 mils

Required Surface Cleanliness Grade: SP6

Daily Working Report for Profile Measurement

<<First Sampling>>

	Location Beam No.	Profile Reading (mils)	Time/Date of Sand Blast	Visual Cleanliness Checking SSPC Grade of Steel Surface
1	1-8-25	3.2	8/25 8:00am	SP10
2	2-8-25	2.3	"	SP10
3	2-8-25	1.3*	"	"
4	3-8-25	1.8	"	SP6
5	3-8-25	2.4	"	"
6	2-8-25	2.2	"	"
7	8-8-25	2.3	"	"
8	8-8-25	2.6	"	"
9	8-8-25	2.9	"	"
10	7-8-25	2.4	"	"

Number of Defect (x1=): 1

If (x1≤1) then Accept *

If (x1=2) Take Second Sampling

If (x1≥3) Reject

<<Second Sampling>>

11				
12				
13				
14				
15				
16				
17				
18				
19				
20				

Number of Defect (x2=):____ Total Number of Defect (x1+x2=)____

If (x1+x2 ≤ 4) then Accept

If (x1+x2 > 4) Reject

Form 3-1-1

Stage-III (**PRIMER INSPECTION FOR FIELD PAINTING**)

Date 8-24-1991

Inspected by Steven

District G.F. Structure # I-65

Contract # HRP-2029

Contractor or Sub. S.G.

Cleanliness of Steel Surface before Painting

(Please Check With a White Napkin) .... Yes No.

Is the Dry Film Thickness Gage calibrated? .... Yes No.

Air-less Spray?.... Yes No. if "No" air supply clean? Yes No.

Name of Paint Manufacturer Dupont

Batch # of paint: B194 and the amount 40 gallons used.

Paint Material Approved? .... Yes No.

Is Paint Well Power Mixed? .... Yes No.

Thinning Approved ..... Yes No.

Time/Date of Priming 2:00 pm 8/24

Time between Blasting & Priming 6 Hrs.(Maximum 24 Hours)

Did the contractor cooperate with INDOT by helping inspectors access the bridge in primer inspection?... Yes No.

Daily Working Ambient Condition: (If more space is needed, record them on the other side of the paper)

Date	8/24	8/24	8/25			
Time	1:00am	2:00pm	1:30pm			
Dry Bulb (F)	60	68	50			
Wet Bulb (F)	55	58	45			
Relative Humid.(%)	73	57	70			
Dew Point (F)	53	49	38			
Steel Temp. (F)	55	59	47			
Steel Temp.- Dew Point	2	10	11			
Wind Speed (MPH)	8	3	5			
Is the Ambience OK?(Y/N)	No.	Yes	Yes			

Weather Comments: Steel Temp. - Dew Point =2 < 5 @ 1:00pm 8/24 Priming is stopped. Priming Resumed at 2:00pm.

<< Detailed Measurement Data >>> Form 3-2- 1

Required Coating Thickness : 2.5 mils

Parameter used: n1=n2=10; c1=1; r1=3; c2=4

Required Sample Size : 10

Seven reading: 2 on bottom of top flange
3 on web
2 on top of bottom flange
1 on vertical edge of bottom flange
2 on bottom of bottom flange.

Use one beam as a "Lot"

x1 : the number of defect in the first sample

x2 : the number of defect in the second sample

Possible Conditions of Acceptance

x1=	x2=
0	
1	
2	0
2	1
2	2

If ($x1=0$ or 1) then Accept
If ($x1= 2$) Take Second Sampling
If ($x1\geq3$) Reject

If ($x1+x2 \leq 4$) then Accept
If ($x1+x2 > 4$) Reject

<<Detailed Measurement Data. Please duplicate if necessary>>

Beam/Lot# 1-8-24, Date of Painting 8/24		Beam/Lot# 2-8-24, Date of Painting 8/24		Beam/Lot# 3-8-24, Date of Painting 8/24	
First Sample	Second Sample	First Sample	Second Sample	First Sample	Second Sample
2.7		2.9		2.2 *	
3.0		2.8		2.4 *	
3.5		3.0		2.6	
2.8		2.9		3.0	
2.6		3.1		3.0	
2.9		3.1		2.2 *	
3.0		2.8		2.5	
3.2		2.9		2.6	
3.3		3.0		2.7	
3.0		3.2		2.8	
x1= 0	x2= x1+x2=	x1= 1	x2= x1+x2=	x1= 3	x2= x1+x2=
If Visual Inspection OK? Yes* No		If Visual Inspection OK? Yes No*		If Visual Inspection OK? Yes No	
Accept* or Reject		Accept or Reject *		Accept or Reject *	

<< Detailed Measurement Data >>> Form 3-2- 2

Beam/Lot# 4-8-24	Date of Painting 8/24
First Sample	Second Sample
2.4 *	3.0
3.1	3.3
3.0	3.0
2.9	2.9
2.8	2.8
2.3 *	3.0
2.5	2.2
2.8	2.6
2.7	2.8
3.0	2.7
x1= 2	x2= 1 x1+x2= 3
If Visual Inspection OK? Yes* No	
Accept* or Reject	

Beam/Lot# 5-8-24	Date of Painting 8/24
First Sample	Second Sample
2.7	2.4 *
3.6	2.3 *
2.1 *	2.8
2.8	2.9
3.3	3.0
3.1	3.1
3.4	3.4
3.0	2.1 *
2.2 *	2.7
2.8	2.6
x1= 2	x2= 3 x1+x2= 5
If Visual Inspection OK? Yes No	
Accept or Reject *	

Beam/Lot# 6-8-24	Date of Painting 8/24
First Sample	Second Sample
2.6	
2.9	
3.3	
3.0	
3.4	
3.8	
3.8	
3.4	
3.0	
3.3	
x1= 0	x2= x1+x2=
If Visual Inspection OK? Yes* No	
Accept* or Reject	

Beam/Lot# 7-8-24	Date of Painting 8/24
First Sample	Second Sample
2.2 *	3.0
3.3	3.3
3.2	3.0
3.9	2.9
3.8	2.8
1.9 *	3.0
2.6	2.2 *
2.7	2.6
3.7	2.8
3.3	2.7
x1= 2	x2= 1 x1+x2= 3
If Visual Inspection OK? Yes* No	
Accept* or Reject	

Beam/Lot# 8-8-24	Date of Painting 8/24
First Sample	Second Sample
2.7	3.4
3.6	3.3
2.1 *	2.8
2.8	2.9
3.3	3.0
3.1	3.1
3.4	3.4
3.0	3.1
2.2 *	2.7
2.8	2.6
x1= 2	x2= 0 x1+x2= 2
If Visual Inspection OK? Yes* No	
Accept* or Reject	

Beam/Lot#	Date of Painting
First Sample	Second Sample
x1=	x2= x1+x2=
If Visual Inspection OK? Yes No	
Accept or Reject	

<< Detailed Measurement Data >>> Form 3-2-3

Required Coating Thickness : 2.5

Parameter used: n1=n2=10; c1=1; r1=3; c2=4

Required Sample Size : 10

Seven reading: 2 on bottom of top flange
3 on web
2 on top of bottom flange
1 on vertical edge of bottom flange
2 on bottom of bottom flange.

Use one beam as a "Lot"

x1 : the number of defect in the first sample

x2 : the number of defect in the second sample

Possible Conditions of Acceptance

x1=	x2=
0	
1	
2	0
2	1
2	2

If (x1=0 or 1) then Accept
If (x1= 2) Take Second Sampling
If (x1≥3) Reject

If (x1+x2 ≤ 4) then Accept
If (x1+x2 > 4) Reject

<<Detailed Measurement Data. Please duplicate if necessary>>

Beam/Lot# 8-8-25 Date of Painting 8/25		Beam/Lot# 7-8-25 Date of Painting 8/25		Beam/Lot# 6-8-25 Date of Painting 8/25	
First Sample	Second Sample	First Sample	Second Sample	First Sample	Second Sample
3.7		3.9			
3.2		3.8			
2.5		4.0			
3.8		4.9			
3.6		3.1			
2.7		3.1			
3.2		3.8			
3.1		3.9			
3.2		2.9			
2.9		3.2			
x1= 0	x2= x1+x2=	x1= 0	x2= x1+x2=	x1=	x2= x1+x2=
If Visual Inspection OK? Yes* No		If Visual Inspection OK? Yes No*		If Visual Inspection OK? Yes No*	
Accept* or Reject		Accept or Reject *		Accept or Reject *	

<< Detailed Measurement Data >>> Form 3-2-4

Beam/Lot# 5-8-25 Date of Painting 8/25	
First Sample	Second Sample
2.4 *	3.0
3.1	3.3
3.0	3.0
2.9	2.9
2.8	2.8
2.3 *	3.0
2.5	2.2
2.8	2.6
2.7	2.8
3.0	2.7
x1= 2	x2= 1 x1+x2= 3
If Visual Inspection OK? Yes* No	
Accept* or Reject	

Beam/Lot# 4-8-25 Date of Painting 8/25	
First Sample	Second Sample
2.7	3.4
3.6	3.3
2.1 *	2.8
2.8	2.9
3.3	3.0
3.1	3.1
3.4	3.4
3.0	3.1
2.2 *	2.7
2.8	2.6
x1= 2	x2= 0 x1+x2= 2
If Visual Inspection OK? Yes* No	
Accept* or Reject	

Beam/Lot# 3-8-25 Date of Painting 8/25	
First Sample	Second Sample
2.6	
2.9	
3.3	
3.0	
3.4	
3.8	
3.8	
3.4	
3.0	
3.3	
x1= 0	x2= x1+x2=
If Visual Inspection OK? Yes* No	
Accept* or Reject	

Beam/Lot# 2-8-25 Date of Painting 8/25	
First Sample	Second Sample
2.2 *	3.0
3.3	3.3
3.2	3.0
3.9	2.9
3.8	2.8
1.9 *	3.0
2.6	2.2 *
2.7	2.6
3.7	2.8
3.3	2.7
x1= 2	x2= 1 x1+x2= 3
If Visual Inspection OK? Yes* No	
Accept* or Reject	

Beam/Lot# 1-8-25 Date of Painting 8/25	
First Sample	Second Sample
2.7	3.4
3.6	3.3
2.1 *	2.8
2.8	2.9
3.3	3.0
3.1	3.1
3.4	3.4
3.0	3.1
2.2 *	2.7
2.8	2.6
x1= 2	x2= 0 x1+x2= 2
If Visual Inspection OK? Yes* No	
Accept* or Reject	

Beam/Lot# Date of Painting	
First Sample	Second Sample
x1=	x2= x1+x2=
If Visual Inspection OK? Yes No	
Accept or Reject	

<<< Summary of Form 3-2. >>>
(Please duplicate if necessary)

Form 3-3

	Beam No. at Span No.	x1=0, 1 Accept x1=2 Take Second Sample x1=3,4,... Reject x1=	x1+x2=1,2,3,4 Accept x1+x2= 5, 6.... Reject x1+x2=	Visual Inspection OK ? Dry Spray Run, Sag Mud-cracking Yes	 No	Accept this Lot ? Yes	 No
1	1-8-24	0		√		√	
2	2-8-24	0			√		√
3	3-8-24	3					√
4	4-8-24	2	3	√		√	
5	5-8-24	2	5			√	
6	6-8-24	0			√		√
7	7-8-24	2	3	√		√	
8	8-8-24	2	2	√		√	
9	8-8-25	0		√		√	
10	7-8-25	0			√		√
11	6-8-25				√		√
12	5-8-25	2	3	√		√	
13	4-8-25	2	2	√		√	
14	3-8-25	0		√			√
15	2-8-25	2	3	√			√
16	1-8-25	2	2	√			√
17							
18							
19							
20							

Form 4-1

Stage-IV

(TOP-COATING / IMMEDIATE-COATING INSPECTION FOR FIELD PAINTING)

Date 8-27-1991

Inspected by Steven

District G.F. Structure # I-65

Contract # HRP-2027

Contract or Sub. G.S.

Cleanliness of Steel Surface before Painting

(Please Check With a White Napkin) .... Yes No

Is the Dry Film Thickness Gage calibrated? .... Yes No.

Air-less Spray?... Yes No. If "No" air supply clean? Yes No.

Name of Paint Manufacturer Depont

Batch # of paint: B203 and its amount is 38 gallons.

Paint Material Approved? .... Yes No.

Is Paint Well Power Mixed? .... Yes No.

Thinning ..... Yes No.

Time/Date of Top-Coating 9:30am 8/27

Time between Priming & Top-Coating 3 Days

Daily Working Ambient Condition: (If more space needed, record data on the other side of this paper)

Date	8/27	8/27				
Time	10:00	1:00pm				
Dry Bulb (F)	60	60				
Wet Bulb (F)	55	54				
Relative Humid.(%)	73	70				
Dew Point (F)	53	52				
Steel Temp. (F)	58	59				
Steel Temp.- Dew Point	5	7				
Wind Speed (MPH)	25	10				
Is the Ambience OK?(Y/N)	No	Yes				

Weather Comments: Speedy Wind at 10:00 am, Stopping Painting. Painting Resumed at 1:00pm

Did the contractor cooperate with INDOT by helping inspectors access the bridge? .... Yes No

<< Detailed Measurement Data for **Field** Inspection>> Form 4-2-<u>1</u>

Required Coating Thickness : <u>5.5 mils</u>
Parameter used: n1=n2=10; c1=1; r1=3; c2=4
Required Sample Size : <u>10</u>
Seven reading: 2 on bottom of top flange
3 on web
2 on top of bottom flange
1 on vertical edge of bottom flange
2 on bottom of bottom flange.
Use one beam as a "Lot"
x1 : the number of defect in the first sample
x2 : the number of defect in the second sample
Possible Conditions of Acceptance

x1=	x2=
0	
1	
2	0
2	1
2	2

If (x1=0 or 1) then Accept
If (x1= 2) Take Second Sampling
If (x1≥3) Reject

If (x1+x2 ≤ 4) then Accept
If (x1+x2 > 4) Reject

<<Detailed Measurement Data. Please duplicate if necessary>>

Beam/Lot# 1-8-27, Date of Painting 8/27		Beam/Lot# 2-8-27, Date of Painting 8/27		Beam/Lot# 3-8-27, Date of Painting 8/27	
First Sample	Second Sample	First Sample	Second Sample	First Sample	Second Sample
5.4 *	6.0	6.7	5.4 *	6.6	
6.1	6.3	6.6	5.3 *	6.9	
6.0	6.0	5.1 *	6.8	6.3	
6.9	6.9	6.8	6.9	6.0	
6.8	6.8	6.3	6.0	6.4	
5.3 *	6.0	7.1	5.1 *	6.8	
6.5	6.6	6.4	6.4	6.8	
6.8	6.6	6.0	6.1	6.4	
6.7	6.8	4.6 *	6.7	6.0	
6.0	6.7	6.8	6.6	6.3	
x1= 2	x2= 0 x1+x2= 2	x1= 2	x2= 3 x1+x2= 5	x1= 0	x2= x1+x2=
If Visual Inspection OK? Yes* No		If Visual Inspection OK? Yes No		If Visual Inspection OK? Yes No	
Accept* or Reject		Accept or Reject		Accept or Reject	

<<Detailed Measurement Data for **Field** Inspection>> Form 4-2-2

Beam/Lot# 4-8-27, Date of Painting 8/27	
First Sample	Second Sample
6.4	
6.1	
6.0	
6.9	
6.8	
7.3	
6.5	
6.8	
6.7	
7.0	
x1= 0	x2= x1+x2=
If Visual Inspection OK? Yes No *	
Accept or Reject *	

Beam/Lot# 5-8-27, Date of Painting 8/27	
First Sample	Second Sample
5.7	
5.6	
6.1	
6.8	
5.3 *	
6.1	
7.4	
7.0	
6.2	
5.8	
x1= 1	x2= x1+x2=
If Visual Inspection OK? Yes* No	
Accept* or Reject	

Beam/Lot# 6-8-27, Date of Painting 8/27	
First Sample	Second Sample
6.6	
6.9	
7.3	
7.0	
6.4	
5.8	
5.8	
6.4	
5.0 *	
7.3	
x1= 0	x2= x1+x2=
If Visual Inspection OK? Yes* No	
Accept* or Reject	

Beam/Lot# 7-8-27, Date of Painting 8/27	
First Sample	Second Sample
5.4 *	5.0 *
6.1	6.3
6.0	6.0
5.9	6.9
5.8	6.8
5.3 *	7.0
5.5	6.2
6.8	6.6
6.7	6.8
6.0	5.7
x1= 2	x2= 1 x1+x2= 3
If Visual Inspection OK? Yes* No	
Accept* or Reject	

Beam/Lot# 8-8-27, Date of Painting 8/27	
First Sample	Second Sample
5.7	
5.6	
6.1	
6.8	
6.3	
7.1	
7.4	
8.0	
6.2	
6.8	
x1= 0	x2= x1+x2=
If Visual Inspection OK? Yes* No	
Accept* or Reject	

Beam/Lot# ____, Date of Painting ____	
First Sample	Second Sample
x1=	x2= x1+x2=
If Visual Inspection OK? Yes No	
Accept or Reject	

<<< Summary of Form 3-2. for **Field** Inspection>>>   Form 4-3
(Please duplicate if necessary)

	Beam No. at Span No.	x1=0, 1 Accept x1=2 Take Second Sample x1=3,4,... Reject	x1+x2=1,2,3,4 Accept x1+x2= 5, 6.... Reject	Visual Inspection OK ? Dry Spray Run, Sag Mud-cracking		Accept this Lot ?	
		x1=	x1+x2=	Yes	No	Yes	No
1	1-8-27	2	2	√		√	
2	2-8-27	2	5				√
3	3-8-27	0		√		√	
4	4-8-27	0			√		√
5	5-8-27	1		√		√	
6	6-8-27	1		√		√	
7	7-8-27	2	3	√		√	
8	8-8-27	0		√		√	
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							

Chapter 12

Conclusion and Recommendation

12.1 Conclusion

The research unveiled many pitfalls that interfere with obtaining adequate quality for INDOT's steel bridge painting. Several possible solutions were proposed. The acceptance plan was developed and incorporated into a format of step-by-step check lists and control charts. Also, the existing specification was revised based on the knowledge obtained from the research. To sum up, the research has made the contributions as summarized below:

1. Twenty interviews were directed to the specialists in both shop and field. From the interviews, many problems that impede good quality for the painting construction were uncovered.

2. More than twenty thousand items of field data were collected from both fabrication shops and the field. These data revealed that an average of 38% of dry film thicknesses were less than the specified limits based on INDOT's specification. This implies that the current specification is not realistic.

3. The core of an acceptance plan for quality assurance is the statistical sampling method. In the research, four different

sampling methods were constructed for painting construction. They were: 1) Variable Single Sampling, 2) Attribute Double Sampling, 3) Variable Single Sampling without Risk Control, and 4) Attribute Proportion Single Sampling. The advantages and disadvantages of these methods for INDOT's painting construction were also compared and tabulated for decision making.

4. A revised standard specification for steel bridge painting is provided for INDOT's decision to revise the current standard specification.

5. An implementable acceptance plan utilizing the attribute double sample method is proposed for the current transition phase. This acceptance plan has been tried both in the field and in shops. Feedback from the inspectors and INDOT officers is incorporated into the plan. The attribute double sampling method, eliminating the need for inspector to have a statistical background, can reduce the sample size and minimize the work loads on inspectors without losing the sampling power. However, the privilege of deciding the sample size is still left to INDOT. When INDOT tries to decide on the sample size, the work load imposed on the inspectors should also be taken into consideration. Too great a work load in a new system may cause poor work and generate counterfeit data on the report.

6. A set of step-by-step checklists and control charts were developed to fulfill the proposed acceptance plan. These checklists and control charts can serve as a manual for inspectors' daily work plans. The quality assurance key questions included: 1) What do we want? 2) How do we order it? 3) How do we make sure that we get what we order? and 4) What do we do if we do not get what we ordered? These four questions were answered in the checklists and control charts. With them, the inspectors know where to inspect, how many measurements are necessary, and how to make acceptance/rejection decisions.

7. A second degree pay factor function was proposed. With this adjustable pay schedule system, INDOT can control the maximum pay factor, in addition to the pay factor for the acceptable and rejectable quality levels. The control of the maximum pay factor will make the adjustable pay schedule more acceptable.

12.2 Recommendations for Future Works

The researchers have several recommendations to help ensure steel bridge painting quality. They are summarized as follows:

1. Designate a painting specialist in each district. Professional jobs need profession personnel. More inspectors' training courses, either formal or informal, will help the quality assurance system. Also, the communications between the

inspectors should be improved to facilitate the exchanging of experiences, and help avoid the same problems in the future.

2. A computerized system can reduce the need for inspectors' statistical background and paper work. A more advance statistical acceptance plan, which has more power, could be adopted and coded into the software. The software will allow the inspectors to simply type in the results of their measurements, and the decisions are made by the computer automatically. Currently, the price of lap top or notebook computers has dropped to an affordable range. With the help of the computer, an efficient, feasible and paper-less inspection process can be achieved.

3. Many parameters, such as ambient conditions, interval between blasting and priming, and mixing of paint material significantly influence the final painting quality. These parameters should be checked carefully while the paint is being applied. Consequently, the inspection of painting cannot wait until the completion of the end product. For this reason, a total end-result specification seems unfeasible at the present time for painting construction. To have a more complete end-result specification, studies to develop new testing technologies for end-painting quality are necessary. Thus, the intermediate inspection could be minimized, or the painting quality could be solely tested from the end results.

4. Human visual inspection is still necessary. The quality parameters, such as surface cleanliness, depend largely on personal judgement, which is apt to be subjective. More qualitative and objective test methods and standards should be developed.

5. Many reports show that the computer image process is an applicable technique in painting inspection. With this technique, the painting quality can be detected by taking photos in the distance, without blocking the traffic, and avoiding the necessity for INDOT inspectors of climbing up and down potentially dangerous work sites. To reduce the inspectors' risk and simplify the inspection process, image processing could be a potentially useful technique to help control the quality.

6. Paint material is one of the key elements in protecting the steel bridge from corrosion. Careful selection of a good painting system is crucial to ensure the paint quality. However, many existing paint materials contain volatile organic compound (VOC) ingredients and lead pigments which cause serious environmental problems. These need to be further investigated. More efficient and safer painting systems need to be identified and developed in order to reduce the life cycle cost and painting efforts (Peart, John, 1988).

7. Adjustable pay schedules are recommended. Currently, if the thickness of the painting film does not meet the specified requirements, the contractor will be asked to put more paint on the existing coating, or to remove the finished painting and replace it. However, if additional paint is put on the existing film, the binding strength between the existing and new paint is questionable, and the product service life would not improve as expected. On the other hand, if the owners insist that the nonconforming painted products be removed and repainted, it could be a waste if the nonconforming painted product still has a significant period of service life. So, an adjustable pay schedule system forms an important function for assuring the quality of highway construction. Many highway specifications have adopted the concept of the adjusted pay schedule into their specifications in the area of pavement. Because of the possibility of receiving less than the full bid price for a low quality project, contractors are compelled to pay more attentions to maintaining the quality of their products.

8. The acceptance for bridges with special configurations, such as truss bridges, or suspension bridges is not developed in this research because of the limited resources. For these types of bridges, more effort on setting a modified sampling scheme is needed. The problems of the deficiency of old fashion design such as box beam, grating, lattice work, and

many other inaccessible areas are still a serious inspection problem.

9. The painters' pre-certification program is highly recommended. With the lump sum contract system for the public works, the lowest bid contractor gets the job, and thereafter the inspectors must inspect carefully and closely to assure the specified quality. Currently, this system does not always function. A pre-certification program can be used to assure contractors' technical abilities and credentials. This program can offset the low bid mentality of possible low quality and better assure the painting quality.

10. Maintenance of the steel bridge is costly in both efforts and money. Steel A588 is a self-protecting steel material. Because no painting is needed on the steel surface, Steel A588 could be a beneficial alternative to the steel bridge where esthetic appearance is of no concern (Peart, John, 1991)

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Appendix 3-1

Summary of the Specifications

form

Different States

CURRENT REQUIREMENTS OF PAINTING CONTRACT
FOR
DIFFERENT STATES

SPECIFICATION # State, Year	Painting Thickness DFT	Blast Clean Requirement	Temperature, Humidity Date Workable	Remark
Indiana 1988 619.** (P279) Indiana 1988 (p283) Painting System No. 1.	<< Primer >> All structure stell shall receive an inorganic zinc silicate primer,includeing contact surfaces of high-strength bolted connections and areas in contact with concrete. <*> Where shere connector are used, the top of the flange shall not be painted. Inorganic Zinc Silicate >= 2.5mils Should less then 6.0 mils on flat surface Vinyl finish coating : >= 3.0 mils Outside surface of outside beams and the shoes assemblies under all expansion joint should be given a second Vinyl finish coat >= 2.5 mils these area Total thickness: >= 8.0 mils	Visible steak shadow discoloration by rust should <= 2/3 of area in any square inch Blasted surface shall be primed the same day	temp. >= 40 deg F not misty No work 11/15 - 4/1	
Indiana 1988 (p284) Painting System No. 2.	<< No Primer >> 1. brownish orange shop paint >= 2.0 mils 2. brown first field coat >= 3.2 mils 3. green finish coat >= 3.0 mils (1) >= 2.0 mils (2) >= 3.2 mils (3) >= 3.0 mils			
The ongoing <SPOT> painting project (1990) contract	Organic Zinc Primer >= 2.5 mils Vinyl finish coat >= 3.0 mils	surface cleanliness ask SSPC- SP 6 (commercial)		

CURRENT REQUIREMENTS OF PAINTING CONTRACT
FOR
DIFFERENT STATES

SPECIFICATION # State, Year	Painting Thickness DFT	Blast Clean Requirement	Temperature, Humidity Date	Remark
Illinois 1988 #509.03 (p365)	(Shop New Steel Structure) Zinc-Silicate-Primer (#712.26, p677) Average >= 3.0 mils Min. in any spot: >= 2.5 mils Total primer: <= 6.0 mils Inaccessible ,Field Contact Surface : 1.0 - 5.0 mils Steel partly embaded in concrete should be painted but where "totally embeded" not be painted	Blast Clean SSPC. SP-10 Near-White blast Profile 1- 2.5 mils paint in 24 hrs	Air & metal temp. >= 40. deg F. humidity: 50 - 90 %	
	(Field New Steel Structure) Zinc-Silicate-Primer (#712.26, p677) Average Total Two-Coat: >= 6.0 mils Min. Total: >= 5.0 mils Primer on filed contact surface shall 1.0 - 5.0 mils Surface in contact with concrete (top of beam and girder) shall be given a shop coat but where stud shear connector shall bot be painted No field paint in the area concrete pour < Three coating System > (primer/high build vinyl/vinyl enamel) Average of Three-Coat: >=7.0 mils Min. any point: >= 6.0 mils	Blast Clean SSPC. SP-10 Near-White blast	Air & metal temp. >= 50. deg F.	

CURRENT REQUIREMENTS OF PAINTING CONTRACT
FOR
DIFFERENT STATES

SPECIFICATION # State, Year	Painting Thickness DFT	Blast Clean Requirement	Temperature, Humidity Date	Remark
Ohio 1987	TYPE-A:	Blast clean to Sa 2.5	For shop painting:	
	Inorganic Zinc Silicate Primer		Air temp. >= 40 deg F.	
#514.05	(p486, #708.15)	Sa:		
(p220)	>=3.0 mils , <=10.0 mils	ASTM D2000 blast clean grade		
	Surface of bolted splice shall <= 5.0 mils			
	Blue-Green Vinyl Finish Coat >= 3.0 mils			
	Total of Two-Coat : >=6.0 mils		For field painting : Air temp. >= 50 deg F. Surface temp. >=40 deg F.	

	TYPE-B : Basic lead-silico-chromate Pigment & linseed oil-alkyd Primer coat: >= 1.5 mils Total three-coat : >= 4.5 mils		Relative Humidity <= 85 %	
Kentucky 1988 #727.08.02 p554 p555	Inorganic Zinc Rich Primer: (#821.04.(B) p714)	Blast to: SSPC SP.10 Near-White Blast Clean Photographic standards will be used to determine the acceptability	Air temp. >= 40 deg F. metal temp. >= 5 deg F. humidity <= 90 %	
	(#729.09.02 p555) DFT >= 3.0-0.5 mils <= 3.0+2.0 mils		No painting 11/15 to 4/1	
		Prior to Painting:		
	Vinyl applied at least 72 hours after primed	Sa 2.5 of SSPC Vis-1		
	Wash Primer is not permitted			

	(#727.09.04, p556) Vinyl Coat DFT. : >= 3.0 mils, <= 5.0 mils	<< Profile >> (p395) > 1.5 mils		
P396	Surface to be field bolted in contact or which will be contact with concrete need 1.5 + or - 0.5 mils (P397)			
	< prime but not vinyl soon -- Salts happen on surface shold be clean >			

CURRENT REQUIREMENTS OF PAINTING CONTRACT
FOR
DIFFERENT STATES

SPECIFICATION # State, Year	Painting Thickness DFT	Blast Clean Requirement	Temperature, Humidity Date	Remark
Wisconsin (1989) p309 (3 coating system)	<< Inorganic-Zinc Primer >> In surface of bolted friction splices of the main menbers DFT: 1.0 - 2.5 mils The top of flange where stud shear connector are to be welded sahll received a "MIST" coating of primer less 1.0 mil All area > 2.5 mils above the surface profile Total no less then 7.0 mils (3.5 mils of vinyl intermediate) (1.0 mils of enamel finish coat) <*> Pinhol use plastic material to cover (p309) Bolt heads, nuts shall be painted in shop (368)	SSPC - SP-10 into concrete shall be at least SP-6		
Michigan (1984)	pretreatment wash primer 0.3-0.5 mils << This system is much different from Inorganic-Zinc primer painting & Vinyl system . Also, it is a old edition Their new edition will be available after July >>			

CURRENT REQUIREMENTS OF PAINTING CONTRACT
FOR
DIFFERENT STATES

SPECIFICATION # State, Year	Painting Thickness DFT	Blast Clean Requirement	Temperature, Humidity Date	Remark
SSPC 1989 V.II	*(p275) Inorganic Zinc-Rich primer: DFT primer : 2.5 - 3.5 mils If 5.0-6.0 mils: must show ' NO ' mudcracking ----------------------------- Specification NO> 4.01-4.05(p107-p122) *(p114) Four-Coat Vinyl Painting System (with Red Lead primer) (for salt Water or chemical use) DFT: Wash Primer 0.3 mils Primer 1.5 mils Total FOUR-COAT 5.5 mils ----------------------------- *(p116) Four-Coat Vinyl Painting System (for salt Water,chemical and corrosive atmosphere), DFT: Primer 1.5 mils Total Four-Coat 6.0 mils ----------------------------- *(p118) Three-Coat Vinyl Painting System (with Wash primer) (for salt Water and Weather Exposure) DFT: Wash Primer 0.3 mils Primer 1.5 mils Total Four-Coat 4.0 mils ----------------------------- *(p120) Four-Coat White Colored Vinyl Painting System (for Fresh Water, chemical and Corrosive Atmosphere) DFT: Wash Primer 0.3 mils Primer 1.3 mils Total Four-Coat 5.0 mils ----------------------------- *(p122) Three-Coat Vinyl Painting System (with Wash and Vinyl Alkyd Finished Coat) (for Atmosphere Exposure) DFT: Wash Primer 0.3 mils Primer 1.5 mils Total Four-Coat 4.0 mils	Blast clean: Near white metal blast SSPC SP-10 profile 1.5-3.5 mils	No painting when temp. < 40. deg. F Chemically Cured Coat: temp. >= 55 deg. F Pot life of the Zinc-Rich Primer: Mixed and ready for application: > 4 hours at: temp. 70 deg. F humidity : 50%	

Appendix 6-1

Statistical Summary

for

Data Collected

The Profile data are taken with Testex Replica Tape
The Dry Film Thickness data are taken with Minitest 4000 gauge

Unit : mil
Mean: average
STD: standard deviation
N: number of measurements taken
Max: maximum thickness
Min: minimum thickness
Co-Eff: coefficient (= STD/Mean)
% out : Percentage of measured data out of required limit
(7-26) : The second visit of Farnsworth

All data measured :

Determinant	Mean	STD	N	Max	Min	Spec.
Profile	2.47	0.29	228	4.20	1.70	1.5-3.5
Primer	3.16	1.20	8535	11.70	0.08	>=2.5
Top-Coat	6.65	2.53	10480	46.80	0.60	>=5.5

<< Profile >>

Location	Mean	STD	N	Max	Min	Co-Eff	SSPC-req	% out	Remark	Date
Shop #1	2.08	0.22	22	2.50	1.70	0.11	1.5-3.5	0.0%		6-28
Shop #2	2.54	0.35	47	3.20	1.90	0.14	1.5-3.5	0.0%		7-10
Shop #3	1.93	0.25	20	2.30	1.50	0.13	1.5-3.5	0.0%		7-26
Shop #4	2.65	0.30	53	3.50	2.00	0.11	1.5-3.5	0.0%		10-1
Shop #5	2.60	0.35	49	4.20	2.10	0.13	1.5-3.5	8.2%		10-2
Shop #6	2.45	0.19	47	2.90	2.00	0.08	1.5-3.5	0.0%		10-19

<< Primer >>

Location	Mean	STD	N	Max	Min	Co-Eff	IDOT-req	% out	Remark	Date
Project #1	1.68	0.84	697	8.10	0.34	0.50	2.5	85.9%		6-11
Project #2	4.33	1.32	1198	10.70	1.34	0.30	2.5	4.6%		6-13
Project #3	2.17	1.10	1372	9.90	0.20	0.51	2.50	69.7%		6-28
Project #4	2.59	1.36	1089	11.60	0.14	0.53	2.50	56.0%		6-28
Project #5	3.82	1.37	964	11.20	0.53	0.36	2.5	14.2%		7-26
Project #6	1.68	0.91	125	4.90	0.08	0.54	2.5	84.8%		7-26
Project #7	2.22	1.51	150	7.90	0.27	0.68	2.5	68.7%		8-22
Project #8	1.44	0.48	174	2.97	0.46	0.33	2.5	96.6%		8-22
Project #9	3.87	1.12	275	8.90	0.88	0.29	2.5	7.6%		8-28
Project #10	4.43	1.48	684	10.50	0.40	0.33	2.5	2.6%		10-1
Project #11	3.05	1.18	653	7.40	0.68	0.39	2.5	36.0%		10-2
Project #12	4.13	1.00	161	7.70	1.93	0.24	2.5	3.1%		10-19
Project #13	3.05	0.93	225	5.50	0.59	0.31	2.5	30.2%		10-19

<< Top Coat >>

Location	Mean	STD	N	Max	Min	Co-Eff	IDOT-req	% out	Remark	Date
Bridge #1	5.09	1.80	2639	13.60	1.66	0.35	5.50	62.6%		6-26
Bridge #2	6.50	2.67	2398	46.80	0.60	0.41	5.50	35.4%		7-12
Bridge #3	7.77	2.09	800	19.30	3.22	0.27	5.50	19.5%		9-28
Bridge #4	8.03	2.25	795	19.10	3.03	0.28	5.50	13.6%		9-28
Bridge #5	5.71	2.35	805	19.10	1.37	0.41	5.50	56.9%		9-19
Bridge #6	6.63	2.22	741	21.10	1.92	0.34	5.50	32.7%		8-28
Bridge #7	7.98	2.68	767	27.90	3.10	0.34	5.50	12.6%		9-13
Bridge #8	6.55	2.52	789	36.00	1.06	0.38	5.50	42.3%		9-13
Bridge #9	7.22	2.20	826	18.60	2.34	0.30	5.50	24.9%		9-13
Bridge #10	8.13	2.47	795	28.30	2.33	0.30	5.50	20.5%		9-13

<< Top Coat of Truss >>

Bridge	Mean	STD	N	Max	Min	Co-Eff	require	% out	Remark	Date
Truss #1	6.84	2.32	3790	43.20	0.81	0.34	5.5	37.6%		6-1

<< Different State >>

<< Primer >>

State	Mean	STD	N	Max	Min	Co-Eff	require	% out	Remark	Date
State #1	4.60	1.30	528	9.20	0.66	0.28	ave(3.0) min(2.5)	4.2%		7-10
State #2	3.05	0.97	439	7.80	0.77	0.32	2.5-5.0	33.5%		7-10
State #3	4.57	1.88	184	10.10	1.59	0.41	3.0-10.0	14.7%		6-13
State #3	5.17	1.30	222	8.50	2.45	0.25	3.0-10.0	4.1%		7-10
State #5	3.76	0.91	281	7.90	1.38	0.24	if 2.5	7.1%		10-19
State #6	3.40	0.96	236	8.60	1.54	0.28	if 2.5	20.3%		10-19
State #7	4.15	1.50	264	11.70	1.30	0.36	if 2.5	10.2%		10-19

Appendix 6-2

Experimental Design

form

SAS

The SAS System

General Linear Models Procedure
Class Level Information

Class	Levels	Values
BRIDGE	18	I69-3..A I69-3..C I70-SH.A I70-SH.C MINNI.A MINNI.C TBEACH.A TBEACH.C THIELE.A THIELE.C TSR1.A TSR1.C TSR331.A TSR331.C TU12.A TU12.C TU30.A TU30.C
COMP	7	1 2 3 4 5 6 7
SECTION	2	AB MID

Number of observations in data set = 10480

General Linear Models Procedure

Dependent Variable: THICK

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	110	27900.23749066	253.63852264	58.11	0.0001
Error	10369	45261.56253090	4.36508463		
Corrected Total	10479	73161.80002156			

R-Square	C.V.	Root MSE	THICK Mean
0.381350	31.42265	2.08927850	6.64895802

Source	DF	Type I SS	Mean Square	F Value	Pr > F
BRIDGE	17	16892.51161008	993.67715353	227.64	0.0001
COMP	6	3976.14267742	662.69044624	151.82	0.0001
SECTION	0	0.00000000	.	.	.
BRIDGE*COMP	87	7031.58320316	80.82279544	18.52	0.0001
COMP*SECTION	0	0.00000000	.	.	.
BRIDGE*SECTION	0	0.00000000	.	.	.

Source	DF	Type III SS	Mean Square	F Value	Pr > F
BRIDGE	16	7887.52375391	492.97023462	112.93	0.0001
COMP	6	4222.03879484	703.67313247	161.20	0.0001
SECTION	0	0.00000000	.	.	.
BRIDGE*COMP	81	6511.56522417	80.38969413	18.42	0.0001
COMP*SECTION	0	0.00000000	.	.	.
BRIDGE*SECTION	0	0.00000000	.	.	.

General Linear Models Procedure
Student-Newman-Keuls test for variable: THICK
NOTE: This test controls the type I experimentwise error rate under the complete null hypothesis but not under partial null hypotheses.

Alpha= 0.05 df= 10369 MSE= 4.365085
WARNING: Cell sizes are not equal.
Harmonic Mean of cell sizes= 5033.588

Number of Means	2
Critical Range	0.0816341

Means with the same letter are not significantly different.

SNK Grouping	Mean	N	SECTION
A	7.52585	4200	AB
B	6.06250	6280	MID

General Linear Models Procedure
Student-Newman-Keuls test for variable: THICK
NOTE: This test controls the type I experimentwise error rate under the complete null hypothesis but not under partial null hypotheses.
Alpha= 0.05 df= 10369 MSE= 4.365085
WARNING: Cell sizes are not equal.
Harmonic Mean of cell sizes= 455.5057

Number of Means	2	3	4	5	6	7	8	9	10
Critical Range	0.2713709	0.3245103	0.3557169	0.3777024	0.3945901	0.4082489	0.419684	0.4294979	0.4380794

Number of Means	11	12	13	14	15	16	17	18
Critical Range	0.4456938	0.4525299	0.4587267	0.4643895	0.4695999	0.4744222	0.4789083	0.4831004

Means with the same letter are not significantly different.

SNK Grouping		Mean	N	BRIDGE
	A	9.6022	360	THIELE.A
	B	9.0470	389	TSR331.A
	C	8.7202	378	TBEACH.A
	D	8.0881	382	TU30.A
	D			
	D	7.9252	360	TSR1.A
	D			
	D	7.8452	385	TU30.C
	E	7.2620	363	MINNI.A
	E			
F	E	7.0845	728	I69-3..A
F	E			
F	E	7.0403	406	TSR331.C
F				
F	G	6.8103	422	TBEACH.C
	G			
H	G	6.6945	391	TU12.A
H	G			
H	G	6.6096	435	THIELE.C
H	G			
H	G	6.5390	350	TU12.C
H	G			
H	G	6.5339	466	TSR1.C
H				
H		6.3712	1600	I69-3..C
	I	5.8685	849	I70-SH.A
	I			
	I	5.7880	426	MINNI.C
	J	4.7215	1790	I70-SH.C

General Linear Models Procedure

Student-Newman-Keuls test for variable: THICK

NOTE: This test controls the type I experimentwise error rate under the complete null hypothesis but not under partial null hypotheses.

Alpha= 0.05 df= 10369 MSE= 4.365085
WARNING: Cell sizes are not equal.
Harmonic Mean of cell sizes= 963.8697

Number of Means	2	3	4	5	6	7
Critical Range	0.1865525	0.2230829	0.2445357	0.2596495	0.2712589	0.2806485

Means with the same letter are not significantly different.

SNK Grouping		Mean	N	COMP
	A	7.29287	272	7
	A			
	A	7.28847	1403	4
	A			
B	A	7.14100	1584	6
B				
B		6.99977	1732	3
	C	6.47972	1861	5
	C			
	C	6.42686	2082	2
	D	5.56098	1546	1

Appendix 7-1

Quality Index --- Percent of Defective Table

Q_U or Q_L	Sample Size														
	3	4	5	7	10	15	20	25	30	35	50	75	100	150	200
0	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00
.1	47.24	46.67	46.44	46.26	46.16	46.10	46.08	46.06	46.05	46.05	46.04	46.03	46.03	46.02	46.02
.2	44.46	43.33	42.90	42.54	42.35	42.24	42.19	42.16	42.15	42.13	42.11	42.10	42.09	42.08	42.08
.3	41.63	40.00	39.37	38.87	38.60	38.44	38.37	38.33	38.31	38.29	38.27	38.25	38.24	38.22	38.22
.31	41.35	39.67	39.02	38.50	38.23	38.06	37.99	37.95	37.93	37.91	37.89	37.87	37.86	37.84	37.84
.32	41.06	39.33	38.67	38.14	37.86	37.69	37.62	37.58	37.55	37.54	37.51	37.49	37.48	37.46	37.46
.33	40.77	39.00	38.32	37.78	37.49.	37.31	37.24	37.20	37.18	37.16	37.13	37.11	37.10	37.09	37.08
.34	40.49	38.67	37.97	37.42	37.12	36.94	36.87	36.83	36.80	36.78	36.75	36.73	36.72	36.71	36.71
.35	40.20	38.33	37.62	37.06	36.75	36.57	36.49	36.45	36.43	36.41	36.38	36.36	36.35	36.33	36.33
.36	39.91	38.00	37.28	36.69	36.38	36.20	36.12	36.08	36.05	36.04	36.01	35.98	35.97	35.96	35.96
.37	39.62	37.67	36.93	36.33	36.02	35.83	35.75	35.71	35.68	35.66	35.63	35.61	35.60	35.59	35.58
.38	39.33	37.33	36.58	35.98	35.65	35.46	35.38	35.34	35.31	35.29	35.26	35.24	35.23	35.22	35.21
.39	39.03	37.00	36.23	35.62	35.29	35.10	35.01	34.97	34.94	34.93	34.89	34.87	34.86	34.85	34.84
.40	38.74	36.67	35.88	35.26	34.93	34.73	34.65	34.60	34.58	34.56	34.53	34.50	34.49	34.48	34.47
.41	38.45	36.33	35.54	34.90	34.57	34.37	34.28	34.24	34.21	34.19	34.16	34.13	34.12	34.11	34.10
.42	38.15	36.00	35.19	34.55	34.21	34.00	33.92	33.87	33.85	33.83	33.79	33.77	33.76	33.74	33.74
.43	37.85	35.67	34.85	34.19	33.85	33.64	33.56	33.51	33.48	33.46	33.43	33.40	33.39	33.38	33.37
.44	37.56	35.33	34.50	33.84	33.49	33.28	33.20	33.15	33.12	33.10	33.07	33.04	33.03	33.02	33.01
.45	37.26	35.00	34.16	33.49	33.13	32.92	32.84	32.79	32.76	32.74	32.71	32.68	32.67	32.66	32.65
.46	36.96	34.67	33.81	33.13	32.78	32.57	32.48	32.43	32.40	32.38	32.35	32.32	32.31	32.30	32.29
.47	36.66	34.33	33.47	32.78	32.42	32.21	32.12	32.07	32.04	32.02	31.99	31.96	31.95	31.94	31.93
.48	36.35	34.00	33.12	32.43	32.07	31.85	31.77	31.72	31.69	31.67	31.63	31.61	31.60	31.58	31.58
.49	36.05	33.67	32.78	32.08	31.72	31.50	31.41	31.36	31.33	31.31	31.28	31.25	31.24	31.23	31.22
.50	35.75	33.33	32.44	31.74	31.37	31.15	31.06	31.01	30.98	30.96	30.93	30.90	30.89	30.87	30.87
.51	35.44	33.00	32.10	31.39	31.02	30.80	30.71	30.66	30.63	30.61	30.57	30.55	30.54	30.52	30.52
.52	35.13	32.67	31.76	31.04	30.67	30.45	30.36	30.31	30.28	30.26	30.23	30.20	30.19	30.17	30.17
.53	34.82	32.33	31.42	30.70	30.32	30.10	30.01	29.96	29.93	29.91	29.88	29.85	29.84	29.83	29.82
.54	34.51	32.00	31.08	30.36	29.98	29.76	29.67	29.62	29.59	29.57	29.53	29.51	29.49	29.48	29.48
.55	34.20	31.67	30.74	30.01	29.64	29.41	29.32	29.27	29.24	29.22	29.19	29.16	29.15	29.14	29.13
.56	33.88	31.33	30.40	29.67	29.29	29.07	28.98	28.93	28.90	28.88	28.85	28.82	28.81	28.79	28.79
.57	33.57	31.00	30.06	29.33	28.95	28.73	28.64	28.59	28.56	28.54	28.51	28.48	28.47	28.45	28.45
.58	33.25	30.67	29.73	28.99	28.61	28.39	28.30	28.25	28.22	28.20	28.17	28.14	28.13	28.12	28.11
.59	32.93	30.33	29.39	28.66	28.28	28.05	27.96	27.92	27.89	27.87	27.83	27.81	27.79	27.78	27.77
.60	32.61	30.00	29.05	28.32	27.94	27.72	27.63	27.58	27.55	27.53	27.50	27.47	27.46	27.45	27.44
.61	32.28	29.67	28.72	27.98	27.60	27.39	27.30	27.25	27.22	27.20	27.16	27.14	27.13	27.11	27.11
.62	31.96	29.33	28.39	27.65	27.27	27.05	26.96	26.92	26.89	26.87	26.83	26.81	26.80	26.78	26.78
.63	31.63	29.00	28.05	27.32	26.94	26.72	26.63	26.59	26.56	26.54	26.50	26.48	26.47	26.45	26.45
.64	31.30	28.67	27.72	26.99	26.61	26.39	26.31	26.26	26.23	26.21	26.18	26.15	26.14	26.13	26.12
.65	30.97	28.33	27.39	26.66	26.28	26.07	25.98	25.93	25.90	25.88	25.85	25.83	25.82	25.80	25.80
.66	30.63	28.00	27.06	26.33	25.96	25.74	25.66	25.61	25.58	25.56	25.53	25.51	25.49	25.48	25.48
.67	30.30	27.67	26.73	26.00	25.63	25.42	25.33	25.29	25.26	25.24	25.21	25.19	25.17	25.16	25.16
.68	29.96	27.33	26.40	25.68	25.31	25.10	25.01	24.97	24.94	24.92	24.89	24.87	24.86	24.84	24.84
.69	29.61	27.00	26.07	25.35	24.99	24.78	24.70	24.65	24.62	24.60	24.57	24.55	24.54	24.53	24.52

Values tabulated are read in percent.

Table for Estimating the Lot Percent Nonconforming Using Standard Deviation Method

Q_U or Q_L	Sample Size														
	3	4	5	7	10	15	20	25	30	35	50	75	100	150	200
.70	29.27	26.67	25.74	25.03	24.67	24.46	24.38	24.33	24.31	24.29	24.26	24.24	24.23	24.21	24.21
.71	28.92	26.33	25.41	24.71	24.35	24.15	24.06	24.02	23.99	23.96	23.95	23.92	23.91	23.90	23.90
.72	28.57	26.00	25.09	24.39	24.03	23.83	23.75	23.71	23.68	23.67	23.64	23.61	23.60	23.59	23.59
.73	28.22	25.67	24.76	24.07	23.72	23.52	23.44	23.40	23.37	23.36	23.33	23.31	23.30	23.29	23.28
.74	27.86	25.33	24.44	23.75	23.41	23.21	23.13	23.09	23.07	23.05	23.02	23.00	22.99	22.98	22.98
.75	27.50	25.00	24.11	23.44	23.10	22.90	22.83	22.79	22.76	22.75	22.72	22.70	22.69	22.68	22.67
.76	27.13	24.67	23.79	23.12	22.79	22.60	22.52	22.48	22.46	22.44	22.42	22.40	22.39	22.38	22.37
.77	26.77	24.33	23.47	22.81	22.48	22.30	22.22	22.18	22.16	22.14	22.12	22.10	22.09	22.08	22.08
.78	26.39	24.00	23.15	22.50	22.18	21.99	21.92	21.89	21.86	21.85	21.82	21.80	21.79	21.78	21.78
.79	26.02	23.67	22.83	22.19	21.87	21.70	21.63	21.59	21.57	21.55	21.53	21.51	21.50	21.49	21.49
.80	25.64	23.33	22.51	21.88	21.57	21.40	21.33	21.29	21.27	21.26	21.23	21.22	21.21	21.20	21.20
.81	25.25	23.00	22.19	21.58	21.27	21.10	21.04	21.00	20.98	20.97	20.94	20.93	20.92	20.91	20.91
.82	24.86	22.67	21.87	21.27	20.98	20.81	20.75	20.71	20.69	20.68	20.65	20.64	20.63	20.62	20.62
.83	24.47	22.33	21.56	20.97	20.68	20.52	20.46	20.42	20.40	20.39	20.37	20.35	20.35	20.34	20.34
.84	24.07	22.00	21.24	20.67	20.39	20.23	20.17	20.14	20.12	20.11	20.09	20.07	20.06	20.06	20.05
.85	23.67	21.67	20.93	20.37	20.10	19.94	19.89	19.86	19.84	19.82	19.80	19.79	19.78	19.78	19.77
.86	23.26	21.33	20.62	20.07	19.81	19.66	19.60	19.57	19.56	19.54	19.53	19.51	19.51	19.50	19.50
.87	22.84	21.00	20.31	19.78	19.52	19.38	19.32	19.30	19.28	19.27	19.25	19.24	19.23	19.22	19.22
.88	22.42	20.67	20.00	19.48	19.23	19.10	19.04	19.02	19.00	18.99	18.98	18.96	18.96	18.95	18.95
.89	21.99	20.33	19.69	19.19	18.95	18.82	18.77	18.74	18.73	18.72	18.70	18.69	18.69	18.68	18.68
.90	21.55	20.00	19.38	18.90	18.67	18.54	18.50	18.47	18.46	18.45	18.43	18.42	18.42	18.41	18.41
.91	21.11	19.67	19.07	18.61	18.39	18.27	18.22	18.20	18.19	18.18	18.17	18.16	18.15	18.15	18.15
.92	20.66	19.33	18.77	18.33	18.11	18.00	17.96	17.94	17.92	17.92	17.90	17.89	17.89	17.88	17.88
.93	20.20	19.00	18.46	18.04	17.84	17.73	17.69	17.67	17.66	17.65	17.64	17.63	17.63	17.62	17.62
.94	19.74	18.67	18.16	17.76	17.57	17.46	17.43	17.41	17.40	17.39	17.38	17.37	17.37	17.36	17.36
.95	19.25	18.33	17.86	17.48	17.29	17.20	17.17	17.15	17.14	17.13	17.12	17.12	17.11	17.11	17.11
.96	18.76	18.00	17.56	17.20	17.03	16.94	16.91	16.89	16.88	16.88	16.87	16.86	16.86	16.86	16.85
.97	18.25	17.67	17.25	16.92	16.76	16.68	16.65	16.63	16.63	16.62	16.61	16.61	16.61	16.60	16.60
.98	17.74	17.33	16.96	16.65	16.49	16.42	16.39	16.38	16.37	16.37	16.36	16.36	16.36	16.36	16.36
.99	17.21	17.00	16.66	16.37	16.23	16.16	16.14	16.13	16.12	16.12	16.12	16.11	16.11	16.11	16.11
1.00	16.67	16.67	16.36	16.10	15.97	15.91	15.89	15.88	15.88	15.87	15.87	15.87	15.87	15.87	15.87
1.01	16.11	16.33	16.07	15.83	15.72	15.66	15.64	15.63	15.63	15.63	15.63	15.62	15.62	15.62	15.62
1.02	15.53	16.00	15.78	15.56	15.46	15.41	15.40	15.39	15.39	15.39	15.38	15.38	15.38	15.38	15.38
1.03	14.93	15.67	15.48	15.30	15.21	15.17	15.15	15.15	15.15	15.15	15.15	15.15	15.15	15.15	15.15
1.04	14.31	15.33	15.19	15.03	14.96	14.92	14.91	14.91	14.91	14.91	14.91	14.91	14.91	14.91	14.91
1.05	13.66	15.00	14.91	14.77	14.71	14.68	14.67	14.67	14.67	14.67	14.68	14.68	14.68	14.68	14.68
1.06	12.98	14.67	14.62	14.51	14.46	14.44	14.44	14.44	14.44	14.44	14.45	14.45	14.45	14.45	14.45
1.07	12.27	14.33	14.33	14.26	14.22	14.20	14.20	14.21	14.21	14.21	14.22	14.22	14.22	14.22	14.23
1.08	11.51	14.00	14.05	14.00	13.97	13.97	13.97	13.98	13.98	13.98	13.99	13.99	14.00	14.00	14.00
1.09	10.71	13.67	13.76	13.75	13.73	13.74	13.74	13.75	13.75	13.76	13.77	13.77	13.77	13.78	13.78

Q_U or Q_L	Sample Size														
	3	4	5	7	10	15	20	25	30	35	50	75	100	150	200
1.10	9.84	13.33	13.48	13.49	13.50	13.51	13.52	13.52	13.53	13.54	13.54	13.55	13.55	13.56	13.56
1.11	8.89	13.00	13.20	13.25	13.26	13.28	13.29	13.30	13.31	13.31	13.32	13.33	13.34	13.34	13.34
1.12	7.82	12.67	12.93	13.00	13.03	13.05	13.07	13.08	13.09	13.10	13.11	13.12	13.12	13.12	13.13
1.13	6.60	12.33	12.65	12.75	12.80	12.83	12.85	12.86	12.87	12.88	12.89	12.90	12.91	12.91	12.92
1.14	5.08	12.00	12.37	12.51	12.57	12.61	12.63	12.65	12.66	12.67	12.68	12.69	12.70	12.70	12.70
1.15	0.29	11.67	12.10	12.27	12.34	12.39	12.42	12.44	12.45	12.46	12.47	12.48	12.49	12.49	12.30
1.16	0.00	11.33	11.83	12.03	12.12	12.18	12.21	12.22	12.24	12.25	12.26	12.28	12.28	12.29	12.29
1.17	0.00	11.00	11.56	11.79	11.90	11.96	12.00	12.02	12.03	12.04	12.06	12.07	12.08	12.08	12.09
1.18	0.00	10.67	11.29	11.56	11.68	11.75	11.79	11.81	11.82	11.84	11.85	11.87	11.88	11.88	11.89
1.19	0.00	10.33	11.02	11.33	11.46	11.54	11.58	11.61	11.62	11.63	11.65	11.67	11.68	11.69	11.69
1.20	0.00	10.00	10.76	11.10	11.24	11.34	11.38	11.41	11.42	11.43	11.46	11.47	11.48	11.49	11.49
1.21	0.00	9.67	10.50	10.87	11.03	11.13	11.18	11.21	11.22	11.24	11.26	11.28	11.29	11.30	11.30
1.22	0.00	9.33	10.23	10.65	10.82	10.93	10.98	11.01	11.03	11.04	11.07	11.09	11.09	11.10	11.11
1.23	0.00	9.00	9.97	10.42	10.61	10.73	10.78	10.81	10.84	10.85	10.88	10.90	10.91	10.91	10.92
1.24	0.00	8.67	9.72	10.20	10.41	10.53	10.59	10.62	10.64	10.66	10.69	10.71	10.72	10.73	10.73
1.25	0.00	8.33	9.46	9.98	10.21	10.34	10.40	10.43	10.46	10.47	10.50	10.52	10.53	10.54	10.55
1.26	0.00	8.00	9.21	9.77	10.00	10.15	10.21	10.25	10.27	10.29	10.32	10.34	10.35	10.36	10.37
1.27	0.00	7.67	8.96	9.55	9.81	9.96	10.02	10.06	10.09	10.10	10.13	10.16	10.17	10.18	10.19
1.28	0.00	7.33	8.71	9.34	9.61	9.77	9.84	9.88	9.90	9.92	9.95	9.98	9.99	10.00	10.01
1.29	0.00	7.00	8.46	9.13	9.42	9.58	9.65	9.70	9.72	9.74	9.78	9.80	9.82	9.83	9.83
1.30	0.00	6.67	8.21	8.93	9.22	9.40	9.48	9.52	9.55	9.57	9.60	9.63	9.64	9.65	9.66
1.31	0.00	6.33	7.97	8.72	9.03	9.22	9.30	9.34	9.37	9.39	9.43	9.46	9.47	9.48	9.49
1.32	0.00	6.00	7.73	8.52	8.85	9.04	9.12	9.17	9.20	9.22	9.26	9.29	9.30	9.31	9.32
1.33	0.00	5.67	7.49	8.32	8.66	8.86	8.95	9.00	9.03	9.05	9.09	9.12	9.13	9.15	9.15
1.34	0.00	5.33	7.25	8.12	8.48	8.69	8.78	8.83	8.86	8.88	8.92	8.95	8.97	8.98	8.99
1.35	0.00	5.00	7.02	7.92	8.30	8.52	8.61	8.66	8.69	8.72	8.76	8.79	8.81	8.82	8.83
1.36	0.00	4.67	6.79	7.73	8.12	8.35	8.44	8.50	8.53	8.55	8.60	8.63	8.65	8.66	8.67
1.37	0.00	4.33	6.56	7.54	7.95	8.18	8.28	8.33	8.37	8.39	8.44	8.47	8.49	8.50	8.51
1.38	0.00	4.00	6.33	7.35	7.77	8.01	8.12	8.17	8.21	8.24	8.25	8.31	8.33	8.35	8.35
1.39	0.00	3.67	6.10	7.17	7.60	7.85	7.96	8.01	8.05	8.08	8.12	8.16	8.18	8.19	8.20
1.40	0.00	3.33	5.88	6.98	7.44	7.69	7.80	7.86	7.90	7.92	7.97	8.01	8.02	8.04	8.05
1.41	0.00	3.00	5.66	6.80	7.27	7.53	7.64	7.70	7.74	7.77	7.82	7.86	7.87	7.89	7.90
1.42	0.00	2.67	5.44	6.62	7.10	7.37	7.49	7.55	7.59	7.62	7.67	7.71	7.73	7.74	7.75
1.43	0.00	2.33	5.23	6.45	6.94	7.22	7.34	7.40	7.44	7.47	7.52	7.56	7.58	7.60	7.61
1.44	0.00	2.00	5.01	6.27	6.78	7.07	7.19	7.26	7.30	7.33	7.38	7.42	7.44	7.46	7.47
1.45	0.00	1.67	4.81	6.10	6.63	6.92	7.04	7.11	7.15	7.18	7.24	7.28	7.30	7.31	7.33
1.46	0.00	1.33	4.60	5.93	6.47	6.77	6.90	6.97	7.01	7.04	7.10	7.14	7.16	7.18	7.19
1.47	0.00	1.00	4.39	5.77	6.32	6.63	6.75	6.83	6.87	6.90	6.96	7.00	7.02	7.04	7.05
1.48	0.00	0.67	4.19	5.60	6.17	6.48	6.61	6.69	6.73	6.77	6.82	6.86	6.88	6.90	6.91
1.49	0.00	0.33	3.99	5.44	6.02	6.34	6.48	6.55	6.60	6.63	6.69	6.73	6.75	6.77	6.78

Q_U or Q_L	Sample Size														
	3	4	5	7	10	15	20	25	30	35	50	75	100	150	200
1.50	0.00	0.00	3.80	5.28	5.87	6.20	6.34	6.41	6.46	6.50	6.55	6.60	6.62	6.64	6.65
1.51	0.00	0.00	3.61	5.13	5.73	6.06	6.20	6.28	6.33	6.36	6.42	6.47	6.49	6.51	6.52
1.52	0.00	0.00	3.42	4.97	5.59	5.93	6.07	6.15	6.20	6.23	6.29	6.34	6.36	6.38	6.39
1.53	0.00	0.00	3.23	4.82	5.45	5.80	5.94	6.02	6.07	6.11	6.17	6.21	6.24	6.26	6.27
1.54	0.00	0.00	3.05	4.67	5.31	5.67	5.81	5.89	5.95	5.98	6.04	6.09	6.11	6.13	6.15
1.55	0.00	0.00	2.87	4.52	5.18	5.54	5.69	5.77	5.82	5.86	5.92	5.97	5.99	6.01	6.02
1.56	0.00	0.00	2.69	4.38	5.05	5.41	5.56	5.65	5.70	5.74	5.80	5.85	5.87	5.89	5.90
1.57	0.00	0.00	2.52	4.24	4.92	5.29	5.44	5.53	5.58	5.62	5.68	5.73	5.75	5.78	5.79
1.58	0.00	0.00	2.35	4.10	4.79	5.16	5.32	5.41	5.46	5.50	5.56	5.61	5.64	5.66	5.67
1.59	0.00	0.00	2.19	3.96	4.66	5.04	5.20	5.29	5.34	5.38	5.45	5.50	5.52	5.54	5.56
1.60	0.00	0.00	2.03	3.83	4.54	4.92	5.09	5.17	5.23	5.27	5.33	5.38	5.41	5.43	5.44
1.61	0.00	0.00	1.87	3.69	4.41	4.81	4.97	5.06	5.12	5.16	5.22	5.27	5.30	5.32	5.33
1.62	0.00	0.00	1.72	3.57	4.30	4.69	4.86	4.95	5.01	5.04	5.11	5.16	5.19	5.21	5.23
1.63	0.00	0.00	1.57	3.44	4.18	4.58	4.75	4.84	4.90	4.94	5.01	5.06	5.08	5.11	5.12
1.64	0.00	0.00	1.42	3.31	4.06	4.47	4.64	4.73	4.79	4.83	4.90	4.95	4.98	5.00	5.01
1.65	0.00	0.00	1.28	3.19	3.95	4.36	4.53	4.62	4.68	4.72	4.79	4.85	4.87	4.90	4.91
1.66	0.00	0.00	1.15	3.07	3.84	4.25	4.43	4.52	4.58	4.62	4.69	4.74	4.77	4.80	4.81
1.67	0.00	0.00	1.02	2.95	3.73	4.15	4.32	4.42	4.48	4.52	4.59	4.64	4.67	4.70	4.71
1.68	0.00	0.00	0.89	2.84	3.62	4.05	4.22	4.32	4.38	4.42	4.49	4.55	4.57	4.60	4.61
1.69	0.00	0.00	0.77	2.73	3.52	3.94	4.12	4.22	4.28	4.32	4.39	4.45	4.47	4.50	4.51
1.70	0.00	0.00	0.66	2.62	3.41	3.84	4.02	4.12	4.18	4.22	4.30	4.35	4.38	4.41	4.42
1.71	0.00	0.00	0.55	2.51	3.31	3.75	3.93	4.02	4.09	4.13	4.20	4.26	4.29	4.31	4.32
1.72	0.00	0.00	0.45	2.41	3.21	3.65	3.83	3.93	3.99	4.04	4.11	4.17	4.19	4.22	4.23
1.73	0.00	0.00	0.36	2.30	3.11	3.56	3.74	3.84	3.90	3.94	4.02	4.08	4.10	4.13	4.14
1.74	0.00	0.00	0.27	2.20	3.02	3.46	3.65	3.75	3.81	3.85	3.93	3.99	4.01	4.04	4.05
1.75	0.00	0.00	0.19	2.11	2.93	3.37	3.56	3.66	3.72	3.77	3.84	3.90	3.93	3.95	3.97
1.76	0.00	0.00	0.12	2.01	2.83	3.28	3.47	3.57	3.63	3.68	3.76	3.81	3.84	3.87	3.88
1.77	0.00	0.00	0.06	1.92	2.74	3.20	3.38	3.48	3.55	3.59	3.67	3.73	3.76	3.78	3.80
1.78	0.00	0.00	0.02	1.83	2.66	3.11	3.30	3.40	3.47	3.51	3.59	3.64	3.67	3.70	3.71
1.79	0.00	0.00	0.00	1.74	2.57	3.03	3.21	3.32	3.38	3.43	3.51	3.56	3.59	3.63	3.63
1.80	0.00	0.00	0.00	1.65	2.49	2.94	3.13	3.24	3.30	3.35	3.43	3.48	3.51	3.54	3.55
1.81	0.00	0.00	0.00	1.57	2.40	2.86	3.05	3.16	3.22	3.27	3.35	3.40	3.43	3.46	3.47
1.82	0.00	0.00	0.00	1.49	2.32	2.79	2.98	3.08	3.15	3.19	3.27	3.33	3.36	3.38	3.40
1.83	0.00	0.00	0.00	1.41	2.25	2.71	2.90	3.00	3.07	3.11	3.19	3.25	3.28	3.31	3.32
1.84	0.00	0.00	0.00	1.34	2.17	2.63	2.82	2.93	2.99	3.04	3.12	3.18	3.21	3.23	3.25
1.85	0.00	0.00	0.00	1.26	2.09	2.56	2.75	2.85	2.92	2.97	3.05	3.10	3.13	3.16	3.17
1.86	0.00	0.00	0.00	1.19	2.02	2.48	2.68	2.78	2.85	2.89	2.97	3.03	3.06	3.09	3.10
1.87	0.00	0.00	0.00	1.12	1.95	2.41	2.61	2.71	2.78	2.82	2.90	2.96	2.99	3.02	3.03
1.88	0.00	0.00	0.00	1.06	1.88	2.34	2.54	2.64	2.71	2.75	2.83	2.89	2.92	2.95	2.96
1.89	0.00	0.00	0.00	0.99	1.81	2.28	2.47	2.57	2.64	2.69	2.77	2.83	2.85	2.88	2.90

Q_U or Q_L	Sample Size														
	3	4	5	7	10	15	20	25	30	35	50	75	100	150	200
1.90	0.00	0.00	0.00	0.93	1.75	2.21	2.40	2.51	2.57	2.62	2.70	2.76	2.79	2.82	2.83
1.91	0.00	0.00	0.00	0.87	1.68	2.14	2.34	2.44	2.51	2.56	2.63	2.69	2.72	2.75	2.77
1.92	0.00	0.00	0.00	0.81	1.62	2.08	2.27	2.38	2.45	2.49	2.57	2.63	2.66	2.69	2.70
1.93	0.00	0.00	0.00	0.76	1.56	2.02	2.21	2.32	2.38	2.43	2.51	2.57	2.60	2.62	2.64
1.94	0.00	0.00	0.00	0.70	1.50	1.96	2.15	2.25	2.32	2.37	2.45	2.51	2.54	2.56	2.58
1.95	0.00	0.00	0.00	0.65	1.44	1.90	2.09	2.19	2.26	2.31	2.39	2.45	2.48	2.50	2.52
1.96	0.00	0.00	0.00	0.60	1.38	1.84	2.03	2.14	2.20	2.25	2.33	2.39	2.42	2.44	2.46
1.97	0.00	0.00	0.00	0.56	1.33	1.78	1.97	2.08	2.14	2.19	2.27	2.33	2.36	2.39	2.40
1.98	0.00	0.00	0.00	0.51	1.27	1.73	1.92	2.02	2.09	2.13	2.21	2.27	2.30	2.33	2.34
1.99	0.00	0.00	0.00	0.47	1.22	1.67	1.86	1.97	2.03	2.08	2.16	2.22	2.25	2.27	2.29
2.00	0.00	0.00	0.00	0.43	1.17	1.62	1.81	1.91	1.98	2.03	2.10	2.16	2.19	2.22	2.23
2.01	0.00	0.00	0.00	0.39	1.12	1.57	1.76	1.86	1.93	1.97	2.05	2.11	2.14	2.17	2.18
2.02	0.00	0.00	0.00	0.36	1.07	1.52	1.71	1.81	1.87	1.92	2.00	2.06	2.09	2.11	2.13
2.03	0.00	0.00	0.00	0.32	1.03	1.47	1.66	1.76	1.82	1.87	1.95	2.01	2.04	2.06	2.08
2.04	0.00	0.00	0.00	0.29	0.98	1.42	1.61	1.71	1.77	1.82	1.90	1.96	1.99	2.01	2.03
2.05	0.00	0.00	0.00	0.26	0.94	1.37	1.56	1.66	1.73	1.77	1.85	1.91	1.94	1.96	1.98
2.06	0.00	0.00	0.00	0.23	0.90	1.33	1.51	1.61	1.68	1.72	1.80	1.86	1.89	1.92	1.93
2.07	0.00	0.00	0.00	0.21	0.86	1.28	1.47	1.57	1.63	1.68	1.76	1.81	1.84	1.87	1.88
2.08	0.00	0.00	0.00	0.18	0.82	1.24	1.42	1.52	1.59	1.63	1.71	1.77	1.79	1.82	1.84
2.09	0.00	0.00	0.00	0.16	0.78	1.20	1.38	1.48	1.54	1.59	1.66	1.72	1.75	1.78	1.79
2.10	0.00	0.00	0.00	0.14	0.74	1.16	1.34	1.44	1.50	1.54	1.62	1.68	1.71	1.73	1.75
2.11	0.00	0.00	0.00	0.12	0.71	1.12	1.30	1.39	1.46	1.50	1.58	1.63	1.66	1.69	1.70
2.12	0.00	0.00	0.00	0.10	0.67	1.08	1.26	1.35	1.42	1.46	1.54	1.59	1.62	1.65	1.66
2.13	0.00	0.00	0.00	0.08	0.64	1.04	1.22	1.31	1.38	1.42	1.50	1.55	1.58	1.61	1.62
2.14	0.00	0.00	0.00	0.07	0.61	1.00	1.18	1.28	1.34	1.38	1.46	1.51	1.54	1.57	1.58
2.15	0.00	0.00	0.00	0.06	0.58	0.97	1.14	1.24	1.30	1.34	1.42	1.47	1.50	1.53	1.54
2.16	0.00	0.00	0.00	0.05	0.55	0.93	1.10	1.20	1.26	1.30	1.38	1.43	1.46	1.49	1.50
2.17	0.00	0.00	0.00	0.04	0.52	0.90	1.07	1.16	1.22	1.27	1.34	1.40	1.42	1.45	1.46
2.18	0.00	0.00	0.00	0.03	0.49	0.87	1.03	1.13	1.19	1.23	1.30	1.36	1.39	1.41	1.42
2.19	0.00	0.00	0.00	0.02	0.46	0.83	1.00	1.09	1.15	1.20	1.27	1.32	1.35	1.38	1.39
2.20	0.000	0.000	0.000	0.015	0.437	0.803	0.968	1.061	1.120	1.161	1.233	1.287	1.314	1.340	1.352
2.21	0.000	0.000	0.000	0.010	0.413	0.772	0.936	1.028	1.087	1.128	1.199	1.253	1.279	1.305	1.318
2.22	0.000	0.000	0.000	0.006	0.389	0.743	0.905	0.996	1.054	1.095	1.166	1.219	1.245	1.271	1.283
2.23	0.000	0.000	0.000	0.003	0.366	0.715	0.875	0.965	1.023	1.063	1.134	1.186	1.212	1.238	1.250
2.24	0.000	0.000	0.000	0.002	0.345	0.687	0.845	0.935	0.992	1.032	1.102	1.154	1.180	1.205	1.218
2.25	0.000	0.000	0.000	0.001	0.324	0.660	0.816	0.905	0.962	1.002	1.071	1.123	1.148	1.173	1.186
2.26	0.000	0.000	0.000	0.000	0.304	0.634	0.789	0.876	0.933	0.972	1.041	1.092	1.117	1.142	1.155
2.27	0.000	0.000	0.000	0.000	0.285	0.609	0.762	0.848	0.904	0.943	1.011	1.062	1.087	1.112	1.124
2.28	0.000	0.000	0.000	0.000	0.267	0.585	0.735	0.821	0.876	0.915	0.982	1.033	1.058	1.082	1.094
2.29	0.000	0.000	0.000	0.000	0.250	0.561	0.710	0.794	0.849	0.887	0.954	1.004	1.029	1.053	1.065

Q_U or Q_L	Sample Size														
	3	4	5	7	10	15	20	25	30	35	50	75	100	150	20
2.30	0.000	0.000	0.000	0.000	0.233	0.538	0.685	0.769	0.823	0.861	0.927	0.977	1.001	1.025	1.0
2.31	0.000	0.000	0.000	0.000	0.218	0.516	0.661	0.743	0.797	0.834	0.900	0.949	0.974	0.997	1.0
2.32	0.000	0.000	0.000	0.000	0.203	0.495	0.637	0.719	0.772	0.809	0.874	0.923	0.947	0.971	0.9
2.33	0.000	0.000	0.000	0.000	0.189	0.474	0.614	0.695	0.748	0.784	0.848	0.897	0.921	0.944	0.9
2.34	0.000	0.000	0.000	0.000	0.175	0.454	0.592	0.672	0.724	0.760	0.824	0.872	0.895	0.915	0.9
2.35	0.000	0.000	0.000	0.000	0.163	0.435	0.571	0.650	0.701	0.736	0.799	0.847	0.870	0.893	0.9
2.36	0.000	0.000	0.000	0.000	0.151	0.416	0.550	0.628	0.678	0.714	0.776	0.823	0.846	0.869	0.8
2.37	0.000	0.000	0.000	0.000	0.139	0.398	0.530	0.606	0.656	0.691	0.753	0.799	0.822	0.845	0.8
2.38	0.000	0.000	0.000	0.000	0.128	0.381	0.510	0.586	0.635	0.670	0.730	0.777	0.799	0.822	0.8
2.39	0.000	0.000	0.000	0.000	0.118	0.364	0.491	0.566	0.614	0.648	0.709	0.754	0.777	0.799	0.8
2.40	0.000	0.000	0.000	0.000	0.109	0.348	0.473	0.546	0.594	0.628	0.687	0.732	0.755	0.777	0.7
2.41	0.000	0.000	0.000	0.000	0.100	0.332	0.455	0.527	0.575	0.608	0.667	0.711	0.733	0.755	0.7
2.42	0.000	0.000	0.000	0.000	0.091	0.317	0.437	0.509	0.555	0.588	0.646	0.691	0.712	0.734	0.7
2.43	0.000	0.000	0.000	0.000	0.083	0.302	0.421	0.491	0.537	0.569	0.627	0.670	0.692	0.713	0.7
2.44	0.000	0.000	0.000	0.000	0.076	0.288	0.404	0.474	0.519	0.551	0.608	0.651	0.672	0.693	0.7
2.45	0.000	0.000	0.000	0.000	0.069	0.275	0.389	0.457	0.501	0.533	0.589	0.632	0.653	0.673	0.6
2.46	0.000	0.000	0.000	0.000	0.063	0.262	0.373	0.440	0.484	0.516	0.571	0.613	0.634	0.654	0.6
2.47	0.000	0.000	0.000	0.000	0.057	0.249	0.359	0.425	0.468	0.499	0.553	0.595	0.615	0.635	0.6
2.48	0.000	0.000	0.000	0.000	0.051	0.237	0.344	0.409	0.452	0.482	0.536	0.577	0.597	0.617	0.6
2.49	0.000	0.000	0.000	0.000	0.046	0.226	0.331	0.394	0.436	0.466	0.519	0.560	0.580	0.600	0.6
2.50	0.000	0.000	0.000	0.000	0.041	0.214	0.317	0.380	0.421	0.451	0.503	0.543	0.563	0.582	0.5
2.51	0.000	0.000	0.000	0.000	0.037	0.204	0.304	0.366	0.407	0.436	0.487	0.527	0.546	0.565	0.5
2.52	0.000	0.000	0.000	0.000	0.033	0.193	0.292	0.352	0.392	0.421	0.472	0.511	0.530	0.549	0.5
2.53	0.000	0.000	0.000	0.000	0.029	0.184	0.280	0.339	0.379	0.407	0.457	0.495	0.514	0.533	0.5
2.54	0.000	0.000	0.000	0.000	0.026	0.174	0.268	0.326	0.365	0.393	0.442	0.480	0.499	0.517	0.5
2.55	0.000	0.000	0.000	0.000	0.023	0.165	0.257	0.314	0.352	0.379	0.428	0.465	0.484	0.502	0.5
2.56	0.000	0.000	0.000	0.000	0.020	0.156	0.246	0.302	0.340	0.366	0.414	0.451	0.469	0.487	0.4
2.57	0.000	0.000	0.000	0.000	0.017	0.148	0.236	0.291	0.327	0.354	0.401	0.437	0.455	0.473	0.4
2.58	0.000	0.000	0.000	0.000	0.015	0.140	0.226	0.279	0.316	0.341	0.388	0.424	0.441	0.459	0.4
2.59	0.000	0.000	0.000	0.000	0.013	0.133	0.216	0.269	0.304	0.330	0.375	0.410	0.428	0.445	0.4
2.60	0.000	0.000	0.000	0.000	0.011	0.125	0.207	0.258	0.293	0.318	0.363	0.398	0.415	0.432	0.4
2.61	0.000	0.000	0.000	0.000	0.009	0.118	0.198	0.248	0.282	0.307	0.351	0.385	0.402	0.419	0.4
2.62	0.000	0.000	0.000	0.000	0.008	0.112	0.189	0.238	0.272	0.296	0.339	0.373	0.390	0.406	0.4
2.63	0.000	0.000	0.000	0.000	0.007	0.105	0.181	0.229	0.262	0.285	0.328	0.361	0.378	0.394	0.4
2.64	0.000	0.000	0.000	0.000	0.005	0.099	0.172	0.220	0.252	0.275	0.317	0.350	0.366	0.382	0.3
2.65	0.000	0.000	0.000	0.000	0.005	0.094	0.165	0.211	0.243	0.265	0.307	0.339	0.355	0.371	0.3
2.66	0.000	0.000	0.000	0.000	0.004	0.088	0.157	0.202	0.233	0.256	0.296	0.328	0.344	0.359	0.3
2.67	0.000	0.000	0.000	0.000	0.003	0.083	0.150	0.194	0.224	0.246	0.286	0.317	0.333	0.348	0.3
2.68	0.000	0.000	0.000	0.000	0.002	0.078	0.143	0.186	0.216	0.237	0.277	0.307	0.322	0.338	0.3
2.69	0.000	0.000	0.000	0.000	0.002	0.073	0.136	0.179	0.208	0.229	0.267	0.297	0.312	0.327	0.3

Q_U or Q_L	Sample Size 3	4	5	7	10	15	20	25	30	35	50	75	100	150	200
2.70	0.000	0.000	0.000	0.000	0.001	0.069	0.130	0.171	0.200	0.220	0.258	0.288	0.302	0.317	0.325
2.71	0.000	0.000	0.000	0.000	0.001	0.064	0.124	0.164	0.192	0.212	0.249	0.278	0.293	0.307	0.315
2.72	0.000	0.000	0.000	0.000	0.000	0.060	0.118	0.157	0.184	0.204	0.241	0.269	0.283	0.298	0.305
2.73	0.000	0.000	0.000	0.000	0.000	0.057	0.112	0.151	0.177	0.197	0.232	0.260	0.274	0.288	0.296
2.74	0.000	0.000	0.000	0.000	0.000	0.053	0.107	0.144	0.170	0.189	0.224	0.252	0.266	0.279	0.286
2.75	0.000	0.000	0.000	0.000	0.000	0.049	0.102	0.138	0.163	0.182	0.216	0.243	0.257	0.271	0.277
2.76	0.000	0.000	0.000	0.000	0.000	0.046	0.097	0.132	0.157	0.175	0.209	0.235	0.249	0.262	0.269
2.77	0.000	0.000	0.000	0.000	0.000	0.043	0.092	0.126	0.151	0.168	0.201	0.227	0.241	0.254	0.260
2.78	0.000	0.000	0.000	0.000	0.000	0.040	0.087	0.121	0.145	0.162	0.194	0.220	0.233	0.246	0.252
2.79	0.000	0.000	0.000	0.000	0.000	0.037	0.083	0.115	0.139	0.156	0.187	0.212	0.225	0.238	0.244
2.80	0.000	0.000	0.000	0.000	0.000	0.035	0.079	0.110	0.133	0.150	0.181	0.205	0.218	0.230	0.237
2.81	0.000	0.000	0.000	0.000	0.000	0.032	0.075	0.105	0.128	0.144	0.174	0.198	0.211	0.223	0.229
2.82	0.000	0.000	0.000	0.000	0.000	0.030	0.071	0.101	0.122	0.138	0.168	0.192	0.204	0.216	0.222
2.83	0.000	0.000	0.000	0.000	0.000	0.028	0.067	0.096	0.117	0.133	0.162	0.185	0.197	0.209	0.215
2.84	0.000	0.000	0.000	0.000	0.000	0.026	0.064	0.092	0.112	0.128	0.156	0.179	0.190	0.202	0.208
2.85	0.000	0.000	0.000	0.000	0.000	0.024	0.060	0.088	0.108	0.122	0.150	0.173	0.184	0.195	0.201
2.86	0.000	0.000	0.000	0.000	0.000	0.022	0.057	0.084	0.103	0.118	0.145	0.167	0.178	0.189	0.195
2.87	0.000	0.000	0.000	0.000	0.000	0.020	0.054	0.080	0.099	0.113	0.139	0.161	0.172	0.183	0.188
2.88	0.000	0.000	0.000	0.000	0.000	0.019	0.051	0.076	0.094	0.108	0.134	0.155	0.166	0.177	0.182
2.89	0.000	0.000	0.000	0.000	0.000	0.017	0.048	0.073	0.090	0.104	0.129	0.150	0.160	0.171	0.176
2.90	0.000	0.000	0.000	0.000	0.000	0.016	0.046	0.069	0.087	0.100	0.125	0.145	0.155	0.165	0.171
2.91	0.000	0.000	0.000	0.000	0.000	0.015	0.043	0.066	0.083	0.096	0.120	0.140	0.150	0.160	0.165
2.92	0.000	0.000	0.000	0.000	0.000	0.013	0.041	0.063	0.079	0.092	0.115	0.135	0.145	0.155	0.160
2.93	0.000	0.000	0.000	0.000	0.000	0.012	0.038	0.060	0.076	0.088	0.111	0.130	0.140	0.149	0.154
2.94	0.000	0.000	0.000	0.000	0.000	0.011	0.036	0.057	0.072	0.084	0.107	0.125	0.135	0.144	0.149
2.95	0.000	0.000	0.000	0.000	0.000	0.010	0.034	0.054	0.069	0.081	0.103	0.121	0.130	0.140	0.144
2.96	0.000	0.000	0.000	0.000	0.000	0.009	0.032	0.051	0.066	0.077	0.099	0.117	0.126	0.135	0.140
2.97	0.000	0.000	0.000	0.000	0.000	0.009	0.030	0.049	0.063	0.074	0.095	0.112	0.121	0.130	0.135
2.98	0.000	0.000	0.000	0.000	0.000	0.008	0.028	0.046	0.060	0.071	0.091	0.108	0.117	0.126	0.130
2.99	0.000	0.000	0.000	0.000	0.000	0.007	0.027	0.044	0.057	0.068	0.088	0.104	0.113	0.122	0.126
3.00	0.000	0.000	0.000	0.000	0.000	0.006	0.025	0.042	0.055	0.065	0.084	0.101	0.109	0.118	0.122
3.01	0.000	0.000	0.000	0.000	0.000	0.006	0.024	0.040	0.052	0.062	0.081	0.097	0.105	0.114	0.118
3.02	0.000	0.000	0.000	0.000	0.000	0.005	0.022	0.038	0.050	0.059	0.078	0.093	0.101	0.110	0.114
3.03	0.000	0.000	0.000	0.000	0.000	0.005	0.021	0.036	0.048	0.057	0.075	0.090	0.098	0.106	0.110
3.04	0.000	0.000	0.000	0.000	0.000	0.004	0.019	0.034	0.045	0.054	0.072	0.087	0.094	0.102	0.106
3.05	0.000	0.000	0.000	0.000	0.000	0.004	0.018	0.032	0.043	0.052	0.069	0.083	0.091	0.099	0.103
3.06	0.000	0.000	0.000	0.000	0.000	0.003	0.017	0.030	0.041	0.050	0.066	0.080	0.088	0.095	0.099
3.07	0.000	0.000	0.000	0.000	0.000	0.003	0.016	0.029	0.039	0.047	0.064	0.077	0.085	0.092	0.096
3.08	0.000	0.000	0.000	0.000	0.000	0.003	0.015	0.027	0.037	0.045	0.061	0.074	0.081	0.089	0.092
3.09	0.000	0.000	0.000	0.000	0.000	0.002	0.014	0.026	0.036	0.043	0.059	0.072	0.079	0.086	0.089

Q_U or Q_L	Sample Size														
	3	4	5	7	10	15	20	25	30	35	50	75	100	150	200
3.10	0.000	0.000	0.000	0.000	0.000	0.002	0.013	0.024	0.034	0.041	0.056	0.069	0.076	0.083	0.086
3.11	0.000	0.000	0.000	0.000	0.000	0.002	0.012	0.023	0.032	0.039	0.054	0.066	0.073	0.080	0.083
3.12	0.000	0.000	0.000	0.000	0.000	0.002	0.011	0.022	0.031	0.038	0.052	0.064	0.070	0.077	0.080
3.13	0.000	0.000	0.000	0.000	0.000	0.002	0.011	0.021	0.029	0.036	0.050	0.061	0.068	0.074	0.077
3.14	0.000	0.000	0.000	0.000	0.000	0.001	0.010	0.019	0.028	0.034	0.048	0.059	0.065	0.071	0.075
3.15	0.000	0.000	0.000	0.000	0.000	0.001	0.009	0.018	0.026	0.033	0.046	0.057	0.063	0.069	0.072
3.16	0.000	0.000	0.000	0.000	0.000	0.001	0.009	0.017	0.025	0.031	0.044	0.055	0.060	0.066	0.069
3.17	0.000	0.000	0.000	0.000	0.000	0.001	0.008	0.016	0.024	0.030	0.042	0.053	0.058	0.064	0.067
3.18	0.000	0.000	0.000	0.000	0.000	0.001	0.007	0.015	0.022	0.028	0.040	0.050	0.056	0.062	0.065
3.19	0.000	0.000	0.000	0.000	0.000	0.001	0.007	0.015	0.021	0.027	0.038	0.049	0.054	0.059	0.062
3.20	0.000	0.000	0.000	0.000	0.000	0.001	0.006	0.014	0.020	0.026	0.037	0.047	0.052	0.057	0.060
3.21	0.000	0.000	0.000	0.000	0.000	0.000	0.006	0.013	0.019	0.024	0.035	0.045	0.050	0.055	0.058
3.22	0.000	0.000	0.000	0.000	0.000	0.000	0.005	0.012	0.018	0.023	0.034	0.043	0.048	0.053	0.056
3.23	0.000	0.000	0.000	0.000	0.000	0.000	0.005	0.011	0.017	0.022	0.032	0.041	0.046	0.051	0.054
3.24	0.000	0.000	0.000	0.000	0.000	0.000	0.005	0.011	0.016	0.021	0.031	0.040	0.044	0.049	0.052
3.25	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.010	0.015	0.020	0.030	0.038	0.043	0.048	0.050
3.26	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.009	0.015	0.019	0.028	0.037	0.041	0.046	0.048
3.27	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.009	0.014	0.019	0.027	0.035	0.040	0.044	0.046
3.28	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.008	0.013	0.017	0.026	0.034	0.038	0.042	0.045
3.29	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.008	0.012	0.016	0.025	0.032	0.037	0.041	0.043
3.30	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.007	0.012	0.015	0.024	0.031	0.035	0.039	0.042
3.31	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.007	0.011	0.015	0.023	0.030	0.034	0.038	0.040
3.32	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.006	0.010	0.014	0.022	0.029	0.032	0.036	0.039
3.33	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.006	0.010	0.013	0.021	0.027	0.031	0.035	0.037
3.34	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.006	0.009	0.013	0.020	0.026	0.030	0.034	0.036
3.35	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.005	0.009	0.012	0.019	0.025	0.029	0.032	0.034
3.36	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.005	0.008	0.011	0.018	0.024	0.028	0.031	0.033
3.37	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.005	0.008	0.011	0.017	0.023	0.026	0.030	0.032
3.38	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.004	0.007	0.010	0.016	0.022	0.025	0.029	0.031
3.39	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.004	0.007	0.010	0.016	0.021	0.024	0.028	0.029
3.40	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.004	0.007	0.009	0.015	0.020	0.023	0.027	0.028
3.41	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.003	0.006	0.009	0.014	0.020	0.022	0.026	0.027
3.42	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.003	0.006	0.008	0.014	0.019	0.022	0.025	0.026
3.43	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.003	0.005	0.008	0.013	0.018	0.021	0.024	0.025
3.44	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.003	0.005	0.007	0.012	0.017	0.020	0.023	0.024
3.45	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.003	0.005	0.007	0.012	0.016	0.019	0.022	0.023
3.46	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.002	0.005	0.007	0.011	0.016	0.018	0.021	0.022
3.47	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.002	0.004	0.006	0.011	0.015	0.017	0.020	0.022
3.48	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.002	0.004	0.006	0.010	0.014	0.017	0.019	0.021
3.49	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.004	0.005	0.010	0.014	0.016	0.019	0.020

Q_U or Q_L	Sample Size														
	3	4	5	7	10	15	20	25	30	35	50	75	100	150	200
3.50	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.003	0.005	0.009	0.013	0.015	0.018	0.019
3.51	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.003	0.005	0.009	0.013	0.015	0.017	0.018
3.52	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.003	0.005	0.008	0.012	0.014	0.017	0.018
3.53	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.003	0.004	0.008	0.012	0.014	0.016	0.017
3.54	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.003	0.004	0.008	0.011	0.013	0.015	0.016
3.55	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.003	0.004	0.007	0.011	0.012	0.015	0.016
3.56	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.002	0.004	0.007	0.010	0.012	0.014	0.015
3.57	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.002	0.003	0.006	0.010	0.011	0.013	0.014
3.58	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.002	0.003	0.006	0.009	0.011	0.013	0.014
3.59	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.002	0.003	0.006	0.009	0.010	0.012	0.013
3.60	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.002	0.003	0.006	0.008	0.010	0.012	0.013
3.61	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.002	0.003	0.005	0.008	0.010	0.011	0.012
3.62	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.002	0.003	0.005	0.008	0.009	0.011	0.012
3.63	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.002	0.005	0.007	0.009	0.010	0.011
3.64	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.002	0.004	0.007	0.008	0.010	0.011
3.65	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.002	0.004	0.007	0.008	0.010	0.010
3.66	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.002	0.004	0.006	0.008	0.009	0.010
3.67	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.002	0.004	0.006	0.007	0.009	0.010
3.68	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.002	0.004	0.006	0.007	0.008	0.009
3.69	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.002	0.003	0.005	0.007	0.008	0.009
3.70	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.002	0.003	0.005	0.006	0.008	0.008
3.71	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.003	0.005	0.006	0.007	0.008
3.72	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.003	0.005	0.006	0.007	0.008
3.73	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.003	0.005	0.006	0.007	0.007
3.74	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.003	0.004	0.005	0.007	0.007
3.75	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.002	0.004	0.005	0.006	0.007
3.76	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.002	0.004	0.005	0.006	0.007
3.77	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.002	0.004	0.005	0.006	0.006
3.78	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.002	0.004	0.004	0.005	0.006
3.79	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.002	0.003	0.004	0.005	0.006
3.80	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.002	0.003	0.004	0.005	0.006
3.81	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.002	0.003	0.004	0.005	0.005
3.82	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.002	0.003	0.004	0.005	0.005
3.83	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.002	0.003	0.004	0.004	0.005
3.84	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.003	0.003	0.004	0.005
3.85	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.002	0.003	0.004	0.004
3.86	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.002	0.003	0.004	0.004
3.87	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.002	0.003	0.004	0.004
3.88	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.002	0.003	0.004	0.004
3.89	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.002	0.003	0.003	0.004
3.90	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.002	0.003	0.003	0.004

Appendix 7-2

Normal Distribution Table

Areas Under the Normal Curve, Proportion of Total Area Under the Curve from $-\infty$ to $(x_i - \mu)/\sigma$

$\frac{x_i - \mu}{\sigma}$	0.09	0.08	0.07	0.06	0.05	0.04	0.03	0.02	0.01	0.00
−3.5	0.00017	0.00017	0.00018	0.00019	0.00019	0.00020	0.00021	0.00022	0.00022	0.00023
−3.4	0.00024	0.00025	0.00026	0.00027	0.00028	0.00029	0.00030	0.00031	0.00033	0.00034
−3.3	0.00035	0.00036	0.00038	0.00039	0.00040	0.00042	0.00043	0.00045	0.00047	0.00048
−3.2	0.00050	0.00052	0.00054	0.00056	0.00058	0.00060	0.00062	0.00064	0.00066	0.00069
−3.1	0.00071	0.00074	0.00076	0.00079	0.00082	0.00085	0.00087	0.00090	0.00094	0.00097
−3.0	0.00100	0.00104	0.00107	0.00111	0.00114	0.00118	0.00122	0.00126	0.00131	0.00135
−2.9	0.0014	0.0014	0.0015	0.0015	0.0016	0.0016	0.0017	0.0017	0.0018	0.0019
−2.8	0.0019	0.0020	0.0021	0.0021	0.0022	0.0023	0.0023	0.0024	0.0025	0.0026
−2.7	0.0026	0.0027	0.0028	0.0029	0.0030	0.0031	0.0032	0.0033	0.0034	0.0035
−2.6	0.0036	0.0037	0.0038	0.0039	0.0040	0.0041	0.0043	0.0044	0.0045	0.0047
−2.5	0.0048	0.0049	0.0051	0.0052	0.0054	0.0055	0.0057	0.0059	0.0060	0.0062
−2.4	0.0064	0.0066	0.0068	0.0069	0.0071	0.0073	0.0075	0.0078	0.0080	0.0082
−2.3	0.0084	0.0087	0.0089	0.0091	0.0094	0.0096	0.0099	0.0102	0.0104	0.0107
−2.2	0.0110	0.0113	0.0116	0.0119	0.0122	0.0125	0.0129	0.0132	0.0136	0.0139
−2.1	0.0143	0.0146	0.0150	0.0154	0.0158	0.0162	0.0166	0.0170	0.0174	0.0179
−2.0	0.0183	0.0188	0.0192	0.0197	0.0202	0.0207	0.0212	0.0217	0.0222	0.0228
−1.9	0.0233	0.0239	0.0244	0.0250	0.0256	0.0262	0.0268	0.0274	0.0281	0.0287
−1.8	0.0294	0.0301	0.0307	0.0314	0.0322	0.0329	0.0336	0.0344	0.0351	0.0359
−1.7	0.0367	0.0375	0.0384	0.0392	0.0401	0.0409	0.0418	0.0427	0.0436	0.0446
−1.6	0.0455	0.0465	0.0475	0.0485	0.0495	0.0505	0.0516	0.0526	0.0537	0.0548
−1.5	0.0559	0.0571	0.0582	0.0594	0.0606	0.0618	0.0630	0.0643	0.0655	0.0668
−1.4	0.0681	0.0694	0.0708	0.0721	0.0735	0.0749	0.0764	0.0778	0.0793	0.0808
−1.3	0.0823	0.0838	0.0853	0.0869	0.0885	0.0901	0.0918	0.0934	0.0951	0.0968
−1.2	0.0985	0.1003	0.1020	0.1038	0.1057	0.1075	0.1093	0.1112	0.1131	0.1151
−1.1	0.1170	0.1190	0.1210	0.1230	0.1251	0.1271	0.1292	0.1314	0.1335	0.1357
−1.0	0.1379	0.1401	0.1423	0.1446	0.1469	0.1492	0.1515	0.1539	0.1562	0.1587
−0.9	0.1611	0.1635	0.1660	0.1685	0.1711	0.1736	0.1762	0.1788	0.1814	0.1841
−0.8	0.1867	0.1894	0.1922	0.1949	0.1977	0.2005	0.2033	0.2061	0.2090	0.2119
−0.7	0.2148	0.2177	0.2207	0.2236	0.2266	0.2297	0.2327	0.2358	0.2389	0.2420
−0.6	0.2451	0.2483	0.2514	0.2546	0.2578	0.2611	0.2643	0.2676	0.2709	0.2743
−0.5	0.2776	0.2810	0.2843	0.2877	0.2912	0.2946	0.2981	0.3015	0.3050	0.3085
−0.4	0.3121	0.3156	0.3192	0.3228	0.3264	0.3300	0.3336	0.3372	0.3409	0.3446
−0.3	0.3483	0.3520	0.3557	0.3594	0.3632	0.3669	0.3707	0.3745	0.3783	0.3821
−0.2	0.3859	0.3897	0.3936	0.3974	0.4013	0.4052	0.4090	0.4129	0.4168	0.4207
−0.1	0.4247	0.4286	0.4325	0.4364	0.4404	0.4443	0.4483	0.4522	0.4562	0.4602
−0.0	0.4641	0.4681	0.4721	0.4761	0.4801	0.4840	0.4880	0.4920	0.4960	0.5000

Areas Under the Normal Curve (*continued*)

$\frac{x_i - \mu}{\sigma}$	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
+0.0	0.5000	0.5040	0.5080	0.5120	0.5160	0.5199	0.5239	0.5279	0.5319	0.5359
+0.1	0.5398	0.5438	0.5478	0.5517	0.5557	0.5596	0.5636	0.5675	0.5714	0.5753
+0.2	0.5793	0.5832	0.5871	0.5910	0.5948	0.5987	0.6026	0.6064	0.6103	0.6141
+0.3	0.6179	0.6217	0.6255	0.6293	0.6331	0.6368	0.6406	0.6443	0.6480	0.6517
+0.4	0.6554	0.6591	0.6628	0.6664	0.6700	0.6736	0.6772	0.6808	0.6844	0.6879
+0.5	0.6915	0.6950	0.6985	0.7019	0.7054	0.7088	0.7123	0.7157	0.7190	0.7224
+0.6	0.7257	0.7291	0.7324	0.7357	0.7389	0.7422	0.7454	0.7486	0.7517	0.7549
+0.7	0.7580	0.7611	0.7642	0.7673	0.7704	0.7734	0.7764	0.7794	0.7823	0.7852
+0.8	0.7881	0.7910	0.7939	0.7967	0.7995	0.8023	0.8051	0.8079	0.8106	0.8133
+0.9	0.8159	0.8186	0.8212	0.8238	0.8264	0.8289	0.8315	0.8340	0.8365	0.8389
−1.0	0.8413	0.8438	0.8461	0.8485	0.8508	0.8531	0.8554	0.8577	0.8599	0.8621
+1.1	0.8643	0.8665	0.8686	0.8708	0.8729	0.8749	0.8770	0.8790	0.8810	0.8830
+1.2	0.8849	0.8869	0.8888	0.8907	0.8925	0.8944	0.8962	0.8980	0.8997	0.9015
+1.3	0.9032	0.9049	0.9066	0.9082	0.9099	0.9115	0.9131	0.9147	0.9162	0.9177
+1.4	0.9192	0.9207	0.9222	0.9236	0.9251	0.9265	0.9279	0.9292	0.9306	0.9319
−1.5	0.9332	0.9345	0.9357	0.9370	0.9382	0.9394	0.9406	0.9418	0.9429	0.9441
+1.6	0.9452	0.9463	0.9474	0.9484	0.9495	0.9505	0.9515	0.9525	0.9535	0.9545
+1.7	0.9554	0.9564	0.9573	0.9582	0.9591	0.9599	0.9608	0.9616	0.9625	0.9633
+1.8	0.9641	0.9649	0.9656	0.9664	0.9671	0.9678	0.9686	0.9693	0.9699	0.9706
+1.9	0.9713	0.9719	0.9726	0.9732	0.9738	0.9744	0.9750	0.9756	0.9761	0.9767
−2.0	0.9773	0.9778	0.9783	0.9788	0.9793	0.9798	0.9803	0.9808	0.9812	0.9817
−2.1	0.9821	0.9826	0.9830	0.9834	0.9838	0.9842	0.9846	0.9850	0.9854	0.9857
−2.2	0.9861	0.9864	0.9868	0.9871	0.9875	0.9878	0.9881	0.9884	0.9887	0.9890
−2.3	0.9893	0.9896	0.9898	0.9901	0.9904	0.9906	0.9909	0.9911	0.9913	0.9916
−2.4	0.9918	0.9920	0.9922	0.9925	0.9927	0.9929	0.9931	0.9932	0.9934	0.9936
−2.5	0.9938	0.9940	0.9941	0.9943	0.9945	0.9946	0.9948	0.9949	0.9951	0.9952
−2.6	0.9953	0.9955	0.9956	0.9957	0.9959	0.9960	0.9961	0.9962	0.9963	0.9964
−2.7	0.9965	0.9966	0.9967	0.9968	0.9969	0.9970	0.9971	0.9972	0.9973	0.9974
−2.8	0.9974	0.9975	0.9976	0.9977	0.9977	0.9978	0.9979	0.9979	0.9980	0.9981
−2.9	0.9981	0.9982	0.9983	0.9983	0.9984	0.9984	0.9985	0.9985	0.9986	0.9986
−3.0	0.99865	0.99869	0.99874	0.99878	0.99882	0.99886	0.99889	0.99893	0.99896	0.99900
−3.1	0.99903	0.99906	0.99910	0.99913	0.99915	0.99918	0.99921	0.99924	0.99926	0.99929
−3.2	0.99931	0.99934	0.99936	0.99938	0.99940	0.99942	0.99944	0.99946	0.99948	0.99950
−3.3	0.99952	0.99953	0.99955	0.99957	0.99958	0.99960	0.99961	0.99962	0.99964	0.99965
−3.4	0.99966	0.99967	0.99969	0.99970	0.99971	0.99972	0.99973	0.99974	0.99975	0.99976
−3.5	0.99977	0.99978	0.99978	0.99979	0.99980	0.99981	0.99981	0.99982	0.99983	0.99983

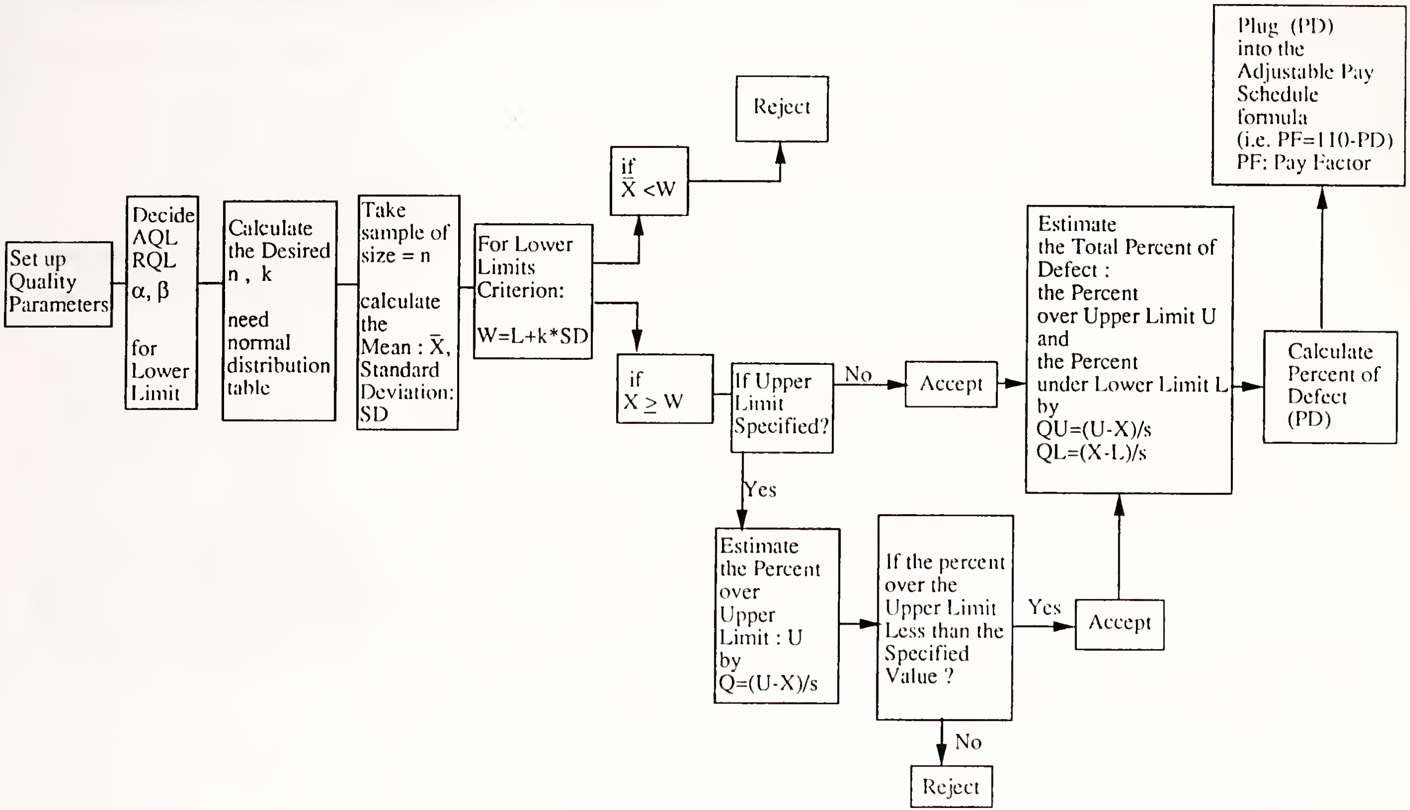
Appendix 7-3

Flow Charts

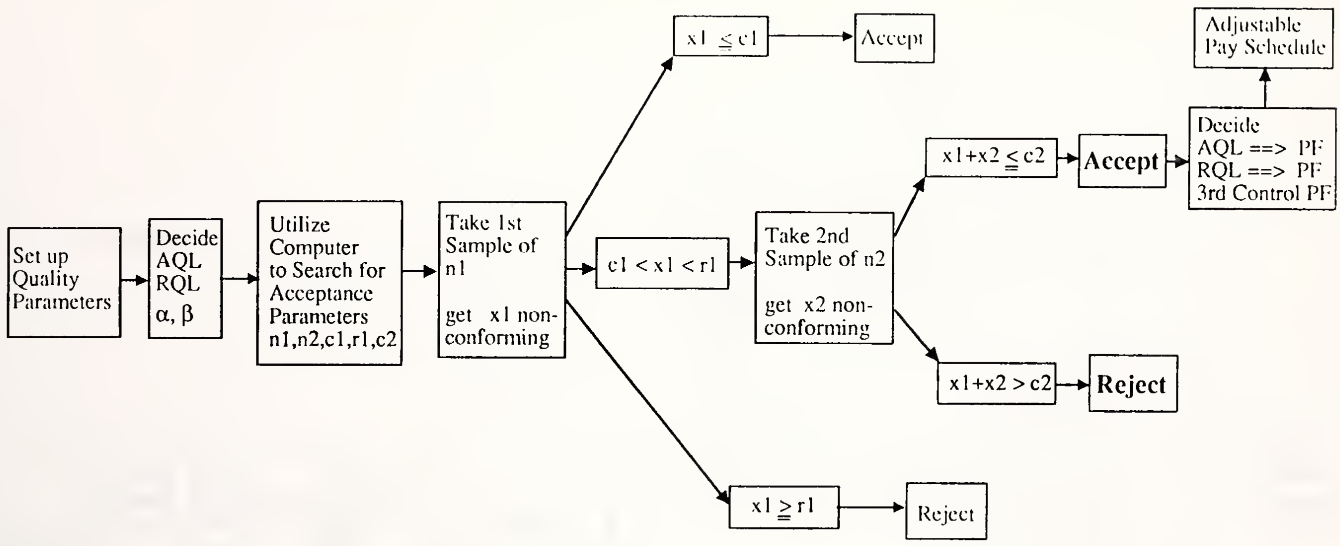
of

Four Acceptance Sampling Plans

Variable Single Sampling Method



Attribute Double Sampling Method



Legend

AQL: Acceptable Quality Level

RQL : Rejectable Quality Level
α : Producer's Risk
β : Buyer's Risk

n1 = 1st Sample Size

n2 = 2nd Sample Size

c1 = 1st Acceptable Number for 1st sample

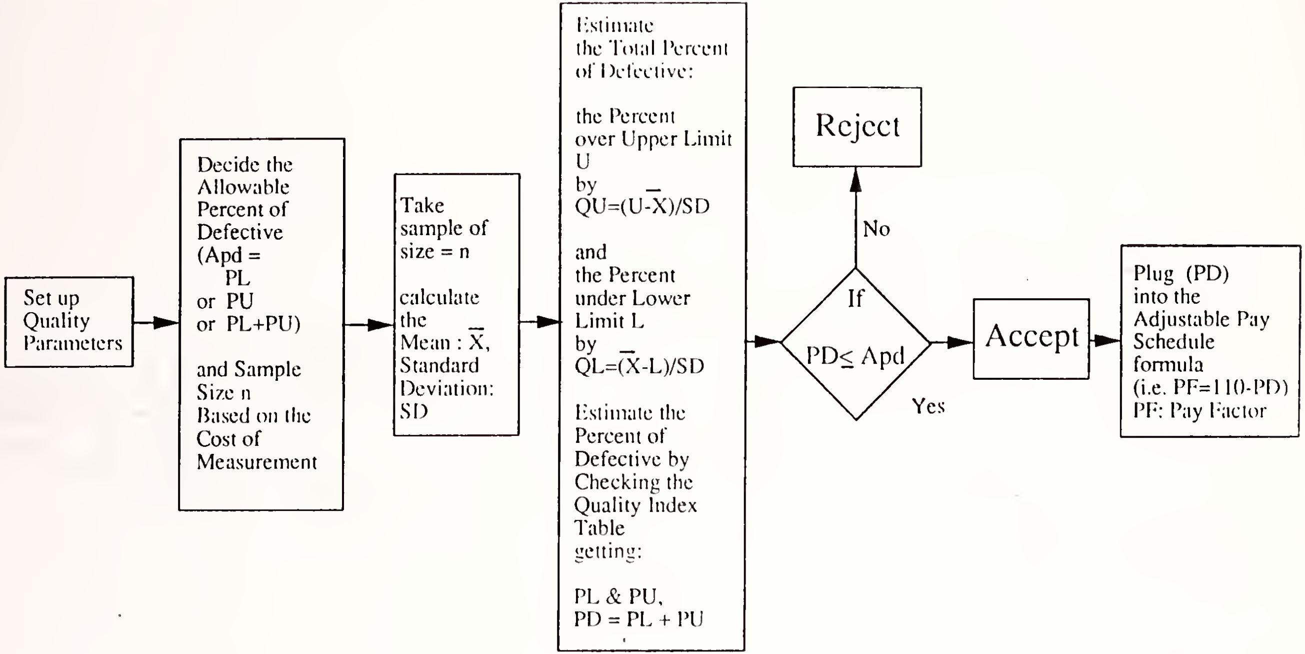
r1 = 1st Rejectable Number for 1st sample

c2 = Accetable Number for 2nd Sample

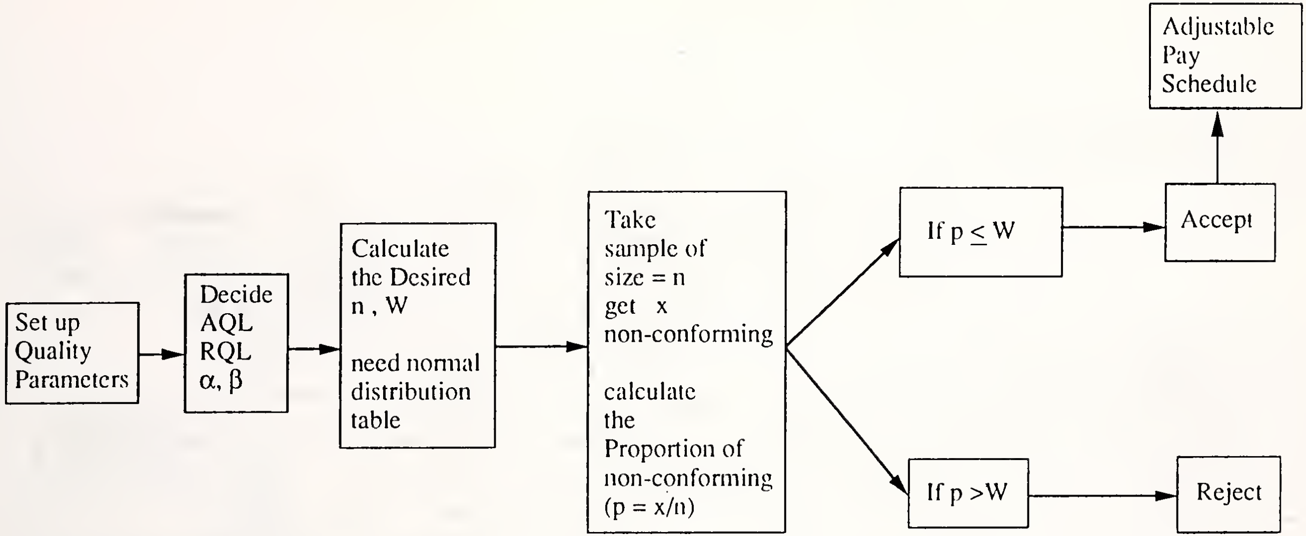
PD = Percent of Defect

PF = Pay Factor

Variable Single Sampling Without Risk Control Method



Attribute Proportion Single Sampling Method



Appendix 7-4

Required Sample Size

Related

to

Error Margin

under

Different

Confidence Levels
and
Percents of Defective

==

Confidence Level= 90.0%

Z()= 1.69

P : Under Lying Percent of Defect

"n" : Sample size

Required Sample Size (n)= (Z^2 * P(1-P) / h^2)

==

P=	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%
Error Margin h=by % error	n=	n=	n=	n=	n=	n=	n=	n=	n=	n=
2%	339	643	910	1142	1339	1499	1624	1714	1767	1785
3%	151	286	405	508	595	666	722	762	785	793
4%	85	161	228	286	335	375	406	428	442	446
5%	54	103	146	183	214	240	260	274	283	286
6%	38	71	101	127	149	167	180	190	196	198
7%	28	52	74	93	109	122	133	140	144	146
8%	21	40	57	71	84	94	102	107	110	112
9%	17	32	45	56	66	74	80	85	87	88
10%	14	26	36	46	54	60	65	69	71	71
11%	11	21	30	38	44	50	54	57	58	59
12%	9	18	25	32	37	42	45	48	49	50
13%	8	15	22	27	32	35	38	41	42	42
14%	7	13	19	23	27	31	33	35	36	36
15%	6	11	16	20	24	27	29	30	31	32
16%	5	10	14	18	21	23	25	27	28	28
17%	5	9	13	16	19	21	22	24	24	25
18%	4	8	11	14	17	19	20	21	22	22
19%	4	7	10	13	15	17	18	19	20	20
20%	3	6	9	11	13	15	16	17	18	18
21%	3	6	8	10	12	14	15	16	16	16

==

Confidence Level = 95.0%
Z()= 1.96
P : Under Lying Percent of Defect
"n" : Sample size
Required Sample Size (n)= (Z^2 * P(1-P) / h^2)

P=	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%
Error Margin h=by % error	n=	n=	n=	n=	n=	n=	n=	n=	n=	n=
2%	456	864	1225	1537	1801	2017	2185	2305	2377	2401
3%	203	384	544	683	800	896	971	1024	1056	1067
4%	114	216	306	384	450	504	546	576	594	600
5%	73	138	196	246	288	323	350	369	380	384
6%	51	96	136	171	200	224	243	256	264	267
7%	37	71	100	125	147	165	178	188	194	196
8%	29	54	77	96	113	126	137	144	149	150
9%	23	43	60	76	89	100	108	114	117	119
10%	18	35	49	61	72	81	87	92	95	96
11%	15	29	40	51	60	67	72	76	79	79
12%	13	24	34	43	50	56	61	64	66	67
13%	11	20	29	36	43	48	52	55	56	57
14%	9	18	25	31	37	41	45	47	49	49
15%	8	15	22	27	32	36	39	41	42	43
16%	7	14	19	24	28	32	34	36	37	38
17%	6	12	17	21	25	28	30	32	33	33
18%	6	11	15	19	22	25	27	28	29	30
19%	5	10	14	17	20	22	24	26	26	27
20%	5	9	12	15	18	20	22	23	24	24
21%	4	8	11	14	16	18	20	21	22	22

==

Confidence Level= 85.0%

Z()= 1.44

P : Under Lying Percent of Defect

"n" : Sample size

Required Sample Size (n)= (Z^2 * P(1-P) / h^2)

==

P=	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%
Error Margin h=by % error	n=	n=	n=	n=	n=	n=	n=	n=	n=	n=
2%	246	467	661	829	972	1089	1179	1244	1283	1296
3%	109	207	294	369	432	484	524	553	570	576
4%	62	117	165	207	243	272	295	311	321	324
5%	39	75	106	133	156	174	189	199	205	207
6%	27	52	73	92	108	121	131	138	143	144
7%	20	38	54	68	79	89	96	102	105	106
8%	15	29	41	52	61	68	74	78	80	81
9%	12	23	33	41	48	54	58	61	63	64
10%	10	19	26	33	39	44	47	50	51	52
11%	8	15	22	27	32	36	39	41	42	43
12%	7	13	18	23	27	30	33	35	36	36
13%	6	11	16	20	23	26	28	29	30	31
14%	5	10	13	17	20	22	24	25	26	26
15%	4	8	12	15	17	19	21	22	23	23
16%	4	7	10	13	15	17	18	19	20	20
17%	3	6	9	11	13	15	16	17	18	18
18%	3	6	8	10	12	13	15	15	16	16
19%	3	5	7	9	11	12	13	14	14	14
20%	2	5	7	8	10	11	12	12	13	13
21%	2	4	6	8	9	10	11	11	12	12

==

Confidence Level= 80.0%

Z()= 1.19

P : Under Lying Percent of Defect

"n" : Sample size

Required Sample Size (n)= (Z^2 * P(1-P) / h^2)

Under lying	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%
Error Margin h=by % error	n=	n=	n=	n=	n=	n=	n=	n=	n=	n=
2%	168	319	451	566	664	743	805	850	876	885
3%	75	142	201	252	295	330	358	378	389	393
4%	42	80	113	142	166	186	201	212	219	221
5%	27	51	72	91	106	119	129	136	140	142
6%	19	35	50	63	74	83	89	94	97	98
7%	14	26	37	46	54	61	66	69	72	72
8%	11	20	28	35	41	46	50	53	55	55
9%	8	16	22	28	33	37	40	42	43	44
10%	7	13	18	23	27	30	32	34	35	35
11%	6	11	15	19	22	25	27	28	29	29
12%	5	9	13	16	18	21	22	24	24	25
13%	4	8	11	13	16	18	19	20	21	21
14%	3	7	9	12	14	15	16	17	18	18
15%	3	6	8	10	12	13	14	15	16	16
16%	3	5	7	9	10	12	13	13	14	14
17%	2	4	6	8	9	10	11	12	12	12
18%	2	4	6	7	8	9	10	10	11	11
19%	2	4	5	6	7	8	9	9	10	10
20%	2	3	5	6	7	7	8	8	9	9
21%	2	3	4	5	6	7	7	8	8	8

Appendix 7-5

Tables

of

the Comparison of Four Acceptance Sampling Plans

Comparison of Different Acceptance Sampling Methods				
Subjects	Methods			
	1. Variable Single Sampling	2. Attribute Double Sampling	3. Variable Single Sampling without Risk Control	4. Attribute Proportion Single Sampling.
Parameters Used to Set up the System	AQL, α RQL, β	Approximate AQL, α RQL, β (integral number)	Allowable Percent of Defect (p)	AQL, α RQL, β
Statistic Theory Used	Normal Distribution Assumption and Utilization (advanced)	Binomial Distribution Computer is Necessary for Searching for Proper System Setting: n1,n2, c1,r1,c2	Use Noncentral t Distribution to Estimate the Percent of Defect	Use Binomial Distribution

System Parameters	n:Sample Size k:Parameter W:Acceptance Criterion =L+k(SD) Compare the Sample Mean with (W)	n1=n2: Sample Size c1:First Acceptance Number r1:First Rejectable Number c2:Second Acceptable Number	n:Sample Size Compare the Estimated Percent of Defect with Allowable Percent of Defect	n:Sample Size W:Acceptance Criterion Compare the Estimated Percent of Defect with (W)
Work that Inspectors Involved	Calculate 1). Sample Mean 2). Standard Deviation (SD) 3). Make Decision	1). Count the x1, x2 (items of defect) 2). Make Decision	Calculate 1). Sample Mean 2). Standard Deviation (SD) 3). Calculate Quality Index 4). Make Decision	Calculate 1). the Percent of Defect by: p=x/n 2). Make Decision

Risk Analysis and Control	Well Risk Analysis Under Desired Control	Well Risk Analysis but Risk Control is Approximated	N/A	Available but Attribute Sampling Do not Supply Accurate Estimate
Estimating of Percent of Defect	Use Quality Index (QI) and Checking the QI table	For One Sample: x1/n1 For Two Sample: x1+x2/n1+n2	Use Quality Index (QI) and Checking the QI table	Roughly x/n Where n: Sample Size x: Number of Defect Items
For Double Side Limits	Use One Critical Limit to Control the Risk, and Quality Index to Check the other Limit	No Problem (for Attribute Sampling, Just Yes/No	Use Q_L & Q_U to get P_L & P_U Totally: $PD=P_L+P_U$	No Problem (for Attribute Sampling, Just Yes/No

Potential for using Adjustable Pay Schedule	Very Good: The Risk Analysis is Solid and Under Control. The Total Percent of Defect can be Accurately Estimated	Not Good: The Attribute Sampling Do not Supply Accurate Estimate of Percent of Defect. Low Confidence at the Pay Schedule Formula	OK: When the Sample Size is Large, the Total Percent of Defect can be Accurately Estimated However, No Control at the Sample Size	Not Good: Although the Risk Analysis is Solid and Under Control. The Total Percent of Defect is NOT Accurately Estimated
Advantage	Well Risk Analysis & Control	The Double Sampling Reduce the Sample Size No Statistic Calculation Necessary for Inspectors Supply a On Time Quality Information	Flexible Sample Size Easy Background Theory	Risk Analysis & Control Available

Disadvant-age	Inspector Need Some Statistic Background Risk Analysis on Only on side Limit	Attribute Sampling Does not Supply Accurate Estimate	No Information About the Risk Analysis & Control No Information About Sample Size	Attribute Sampling Does not Supply Accurate Estimate The Estimated Percent of Defect: (x/n) is a Step Value So, Double Attribute Sampling is More Reality

Appendix 7-6

Attribute Double Sampling Plan

under

Different Combination of Decision Parameters

ATTRIBUTE DOUBLE SAMPLING PLAN
UNDER
DIFFERENT COMBINATION OF DECISION PARAMETERS

```
SAMPLE SIZE == 7
=====================================================
 n1= 7      n2= 7     c1= 0      r1= 2      c2= 1

 ==>  AQL=   3%       Alpha Risk = 5%
 ==>  RQL=  37%        Beta Risk = 5%
=====================================================
 n1= 7      n2= 7     c1= 0      r1= 2      c2= 2

 ==>  AQL=   5%       Alpha Risk = 5%
 ==>  RQL=  40%        Beta Risk = 5%
=====================================================
 n1= 7      n2= 7     c1= 0      r1= 2      c2= 3

 ==>  AQL=   6%       Alpha Risk = 5%
 ==>  RQL=  44%        Beta Risk = 5%
=====================================================
 n1= 7      n2= 7     c1= 0      r1= 2      c2= 4

 ==>  AQL=   6%       Alpha Risk = 5%
 ==>  RQL=  48%        Beta Risk = 5%
=====================================================
 n1= 7      n2= 7     c1= 0      r1= 3      c2= 2

 ==>  AQL=   7%       Alpha Risk = 5%
 ==>  RQL=  41%        Beta Risk = 5%
=====================================================
 n1= 7      n2= 7     c1= 0      r1= 3      c2= 3

 ==>  AQL=  10%       Alpha Risk = 5%
 ==>  RQL=  47%        Beta Risk = 5%
=====================================================
 n1= 7      n2= 7     c1= 0      r1= 3      c2= 4

 ==>  AQL=  12%       Alpha Risk = 5%
 ==>  RQL=  53%        Beta Risk = 5%
=====================================================
 n1= 7      n2= 7     c1= 1      r1= 3      c2= 2

 ==>  AQL=   8%       Alpha Risk = 5%
 ==>  RQL=  53%        Beta Risk = 5%
=====================================================
 n1= 7      n2= 7     c1= 1      r1= 3      c2= 3

 ==>  AQL=  11%       Alpha Risk = 5%
 ==>  RQL=  54%        Beta Risk = 5%
=====================================================
```

ATTRIBUTE DOUBLE SAMPLING PLAN
UNDER
DIFFERENT COMBINATION OF DECISION PARAMETERS

SAMPLE SIZE == 8

```
=====================================================
 n1= 8     n2= 8    c1= 0      r1= 2      c2= 1

 ==>  AQL=   3%       Alpha Risk = 5%
 ==>  RQL=  33%        Beta Risk = 5%
=====================================================
 n1= 8     n2= 8    c1= 0      r1= 2      c2= 2

 ==>  AQL=   5%       Alpha Risk = 5%
 ==>  RQL=  36%        Beta Risk = 5%
=====================================================
 n1= 8     n2= 8    c1= 0      r1= 2      c2= 3

 ==>  AQL=   5%       Alpha Risk = 5%
 ==>  RQL=  40%        Beta Risk = 5%
=====================================================
 n1= 8     n2= 8    c1= 0      r1= 2      c2= 4

 ==>  AQL=   5%       Alpha Risk = 5%
 ==>  RQL=  43%        Beta Risk = 5%
=====================================================
 n1= 8     n2= 8    c1= 0      r1= 3      c2= 2

 ==>  AQL=   6%       Alpha Risk = 5%
 ==>  RQL=  37%        Beta Risk = 5%
=====================================================
 n1= 8     n2= 8    c1= 0      r1= 3      c2= 3

 ==>  AQL=   9%       Alpha Risk = 5%
 ==>  RQL=  42%        Beta Risk = 5%
=====================================================
 n1= 8     n2= 8    c1= 0      r1= 3      c2= 4

 ==>  AQL=  11%       Alpha Risk = 5%
 ==>  RQL=  48%        Beta Risk = 5%
=====================================================
 n1= 8     n2= 8    c1= 1      r1= 3      c2= 2

 ==>  AQL=   7%       Alpha Risk = 5%
 ==>  RQL=  48%        Beta Risk = 5%
=====================================================
 n1= 8     n2= 8    c1= 1      r1= 3      c2= 3

 ==>  AQL=  10%       Alpha Risk = 5%
 ==>  RQL=  49%        Beta Risk = 5%
=====================================================
```

ATTRIBUTE DOUBLE SAMPLING PLAN
UNDER
DIFFERENT COMBINATION OF DECISION PARAMETERS

SAMPLE SIZE == 9

```
=============================================================
 n1= 9      n2= 9     c1= 0       r1= 2       c2= 2

 ==>  AQL=   4%       Alpha Risk = 5%
 ==>  RQL=  33%        Beta Risk = 5%
=============================================================
 n1= 9      n2= 9     c1= 0       r1= 2       c2= 3

 ==>  AQL=   5%       Alpha Risk = 5%
 ==>  RQL=  36%        Beta Risk = 5%
=============================================================
 n1= 9      n2= 9     c1= 0       r1= 2       c2= 4

 ==>  AQL=   5%       Alpha Risk = 5%
 ==>  RQL=  39%        Beta Risk = 5%
=============================================================
 n1= 9      n2= 9     c1= 0       r1= 3       c2= 2

 ==>  AQL=   5%       Alpha Risk = 5%
 ==>  RQL=  34%        Beta Risk = 5%
=============================================================
 n1= 9      n2= 9     c1= 0       r1= 3       c2= 3

 ==>  AQL=   8%       Alpha Risk = 5%
 ==>  RQL=  38%        Beta Risk = 5%
=============================================================
 n1= 9      n2= 9     c1= 0       r1= 3       c2= 4

 ==>  AQL=  10%       Alpha Risk = 5%
 ==>  RQL=  43%        Beta Risk = 5%
=============================================================
 n1= 9      n2= 9     c1= 1       r1= 3       c2= 2

 ==>  AQL=   7%       Alpha Risk = 5%
 ==>  RQL=  44%        Beta Risk = 5%
=============================================================
 n1= 9      n2= 9     c1= 1       r1= 3       c2= 3

 ==>  AQL=   8%       Alpha Risk = 5%
 ==>  RQL=  44%        Beta Risk = 5%
=============================================================
 n1= 9      n2= 9     c1= 1       r1= 3       c2= 4

 ==>  AQL=  10%       Alpha Risk = 5%
 ==>  RQL=  46%        Beta Risk = 5%
=============================================================
```

ATTRIBUTE DOUBLE SAMPLING PLAN
UNDER
DIFFERENT COMBINATION OF DECISION PARAMETERS

SAMPLE SIZE == 10

```
======================================================
 n1=10      n2=10     c1= 0       r1= 2       c2= 1

 ==>  AQL=   3%        Alpha Risk = 5%
 ==>  RQL=  27%         Beta Risk = 5%
======================================================
 n1=10      n2=10     c1= 0       r1= 2       c2= 2

 ==>  AQL=   4%        Alpha Risk = 5%
 ==>  RQL=  30%         Beta Risk = 5%
======================================================
 n1=10      n2=10     c1= 0       r1= 2       c2= 3

 ==>  AQL=   4%        Alpha Risk = 5%
 ==>  RQL=  33%         Beta Risk = 5%
======================================================
 n1=10      n2=10     c1= 0       r1= 2       c2= 4

 ==>  AQL=   4%        Alpha Risk = 5%
 ==>  RQL=  36%         Beta Risk = 5%
======================================================
 n1=10      n2=10     c1= 0       r1= 2       c2= 5

 ==>  AQL=   4%        Alpha Risk = 5%
 ==>  RQL=  38%         Beta Risk = 5%
======================================================
 n1=10      n2=10     c1= 0       r1= 3       c2= 2

 ==>  AQL=   5%        Alpha Risk = 5%
 ==>  RQL=  31%         Beta Risk = 5%
======================================================
 n1=10      n2=10     c1= 0       r1= 3       c2= 3

 ==>  AQL=   7%        Alpha Risk = 5%
 ==>  RQL=  35%         Beta Risk = 5%
======================================================
 n1=10      n2=10     c1= 0       r1= 3       c2= 4

 ==>  AQL=   9%        Alpha Risk = 5%
 ==>  RQL=  39%         Beta Risk = 5%
======================================================
 n1=10      n2=10     c1= 0       r1= 3       c2= 5

 ==>  AQL=   9%        Alpha Risk = 5%
 ==>  RQL=  43%         Beta Risk = 5%
======================================================
```

```
============================================================
 n1=10      n2=10     c1= 0       r1= 4       c2= 3

 ==>  AQL=   8%       Alpha Risk = 5%
 ==>  RQL=  36%        Beta Risk = 5%
============================================================
 n1=10      n2=10     c1= 0       r1= 4       c2= 4

 ==>  AQL=  11%       Alpha Risk = 5%
 ==>  RQL=  41%        Beta Risk = 5%
============================================================
 n1=10      n2=10     c1= 0       r1= 4       c2= 5

 ==>  AQL=  13%       Alpha Risk = 5%
 ==>  RQL=  45%        Beta Risk = 5%
============================================================
 n1=10      n2=10     c1= 0       r1= 5       c2= 4

 ==>  AQL=  11%       Alpha Risk = 5%
 ==>  RQL=  41%        Beta Risk = 5%
============================================================
 n1=10      n2=10     c1= 0       r1= 5       c2= 5

 ==>  AQL=  14%       Alpha Risk = 5%
 ==>  RQL=  46%        Beta Risk = 5%
============================================================
 n1=10      n2=10     c1= 1       r1= 3       c2= 2

 ==>  AQL=   6%       Alpha Risk = 5%
 ==>  RQL=  40%        Beta Risk = 5%
============================================================
 n1=10      n2=10     c1= 1       r1= 3       c2= 3

 ==>  AQL=   8%       Alpha Risk = 5%
 ==>  RQL=  41%        Beta Risk = 5%
============================================================
 n1=10      n2=10     c1= 1       r1= 3       c2= 4

 ==>  AQL=   9%       Alpha Risk = 5%
 ==>  RQL=  42%        Beta Risk = 5%
============================================================
 n1=10      n2=10     c1= 1       r1= 3       c2= 5

 ==>  AQL=   9%       Alpha Risk = 5%
 ==>  RQL=  45%        Beta Risk = 5%
============================================================
 n1=10      n2=10     c1= 1       r1= 4       c2= 3

 ==>  AQL=   8%       Alpha Risk = 5%
 ==>  RQL=  41%        Beta Risk = 5%
============================================================
```

```
================================================================
 n1=10      n2=10     c1= 1       r1= 4       c2= 4

 ==>  AQL=  11%       Alpha Risk = 5%
 ==>  RQL=  43%        Beta Risk = 5%
================================================================
 n1=10      n2=10     c1= 1       r1= 4       c2= 5

 ==>  AQL=  13%       Alpha Risk = 5%
 ==>  RQL=  47%        Beta Risk = 5%
================================================================
 n1=10      n2=10     c1= 1       r1= 5       c2= 4

 ==>  AQL=  11%       Alpha Risk = 5%
 ==>  RQL=  43%        Beta Risk = 5%
================================================================
 n1=10      n2=10     c1= 1       r1= 5       c2= 5

 ==>  AQL=  15%       Alpha Risk = 5%
 ==>  RQL=  47%        Beta Risk = 5%
================================================================
 n1=10      n2=10     c1= 2       r1= 4       c2= 3

 ==>  AQL=  10%       Alpha Risk = 5%
 ==>  RQL=  51%        Beta Risk = 5%
================================================================
 n1=10      n2=10     c1= 2       r1= 4       c2= 4

 ==>  AQL=  12%       Alpha Risk = 5%
 ==>  RQL=  51%        Beta Risk = 5%
================================================================
 n1=10      n2=10     c1= 2       r1= 4       c2= 5

 ==>  AQL=  14%       Alpha Risk = 5%
 ==>  RQL=  52%        Beta Risk = 5%
================================================================
 n1=10      n2=10     c1= 2       r1= 5       c2= 4

 ==>  AQL=  13%       Alpha Risk = 5%
 ==>  RQL=  51%        Beta Risk = 5%
================================================================
 n1=10      n2=10     c1= 2       r1= 5       c2= 5

 ==>  AQL=  15%       Alpha Risk = 5%
 ==>  RQL=  52%        Beta Risk = 5%
================================================================
```

Appendix 9-1

Revised Specification

for

Steel Bridge Painting Contract

Suggested Revision to Standard Specifications for
Painting Steel Bridges - Section 619
for
State of Indiana - Department of Highways
Draft 1/10/92

This revision is generated as part of Joint Highway Research Project "Development of Quality Assurance Specifications for Bridge Painting Contracts", Indiana HPR-2029-(027), NCP 4E4C0232.

Joint Highway Research Project, Purdue University
School of Civil Engineering, Department of Construction Engineering and Management, Luh-Maan Chang, Machine Hsie, David Unkefer, Bob Schmitt (Purdue University); Murray Cantrall, K. R. Hoover, Bob Lowry, D. Lawrence, W. C. Johnson (INDOT); P. Hoffman, J. Hare, J. Peart, Steve Toillion (FHWA).

The focus of new QA specification is encouraging INDOT and its contractors towards greater sensitivity to quality and teamwork. Greater latitude is given to contractor as to how he accomplishes work and consequently greater responsibility for the quality of the final product. It introduces a new method for statistical inspection and acceptance of work performed with an option to add an Adjustable Pay Schedule to provide incentives for an excellent quality final product. This is the final draft of the proposed new specification and it is anticipated there will be further changes as review feedback is received.

The goal of this revision is to create a Quality Assurance (QA) specification which is end result oriented so that INDOT is not telling its contractors how to do the work, but rather what is the end result required. However, because many paint contractors have become dependent on INDOT to provide Quality Control (QC), it is best to transition the responsibility for this to them over time, say one or two years, so as not to overwhelm them. For this reason and also to allow INDOT final judgement on whether to include certain items in the specification, questionable items have been bracketed [] in the following. The brackets indicate that the researchers do not consider these items end result oriented, but rather recipe style, and feel they should ultimately be removed from a QA specification. One reason recipe type items have been included in this specification is for reference material for INDOT's inspectors. Therefore, one suggestion is to develop a separate "Inspector's Manual" which would complement the Standard Specification and allow INDOT to remove recipe type language.

Also in the following, bold text represents existing 1988 INDOT specifications and non-bold is new material. Some material from the 1988 INDOT has been deleted or changed and a close comparison is required to understand all revisions. Underlined material indicates items to be added/deleted based on a review by INDOT and which may be deleted at their disgression. Asterisks are in areas where revisions have been made since the last draft (10/1/91).

Sources for new spec include:
- Illinois Department of Transportation Standard Specifications, including "Special Provision for Cleaning and Painting Existing Steel Structures, Effective August 1, 1990"
- Steel Structures Painting Council (SSPC) Manual
- Specifications for painting inspection (section 09900) from Construction Inspection Handbook by James J. O'brien
- FHA report on Quality Assurance
- Recommendations from the SAC for this project
- Interviews with contractors and INDOT inspectors
- (future?) questionnaire to contractors and pertinent associations
- INDOT recent contracts with special provisions

file REV1892.SPC

QA Spec for INDOT Bridge Painting
Draft 1/8/92

Reference current (1988) INDOT spec (SECTION 619) for application of paint. There are other sections referred to in this one which should be reviewed and revised as necessary to correspond with these changes (i.e. section 908 deals with paint materials).

SECTION 619 - PAINTING

Table of Contents

619.01 Scope of work. This work shall consist of preparing surfaces and furnishing and applying paint in accordance with these specifications or as directed, and all incidental work.

MATERIALS

619.02 Materials. Materials shall be in accordance with the following or as specified in the contract:

?	Brownish Orange Shop Paint (lead chromate primer)	908.02(a)
?	Brown First Field Coat (lead chromate primer)	908.02(b)
	Inorganic Zinc Silicate Primer	908.02(d)
	Vinyl Finish Paint	908.02(e)
?	Green Finish Coat (lead chromate).	908.02(c)
	Black Field Paint (Finish Coat).	908.04(c)
	White Field Paint (Finish Coat).	908.04(b)

[Following are suggested for review]

Lead and chromate free primer. . . . . 908?
Alkyd coat
Vinyl Enamel Finish Coat
Aluminum Epoxy Mastic Primer

Thinning is prohibited except for waterborne systems.

When thinning is prohibited, the unit weight shall be the same as the manufactured unit weight in pounds per gallon, plus or minus 1.0%. [If the unit weight does not fall within this range, the contractor must take corrective action. The contractor may try additional mixing to correct the problem. If additional mixing cannot correct the paint, it shall be rejected. When thinning is allowed, the test procedures will be those as established by the Department. Any paint that has been applied that does not meet the weight per gallon requirements shall be removed and reapplied at the contractors expense.]

The prime, intermediate and finish coats shall all be supplied by the same paint manufacturer to insure compatibility. All paint shall be delivered to the jobsite original containers with labels providing the manufacturer, brand name, lot number, date manufactured, shelf life and any other information required to match against the batch certification.

Paint shall not be stored at temperatures below 40 degrees F or below that specified by the manufacturer.

Prior to approval and use of any paint, the manufacturer shall submit a notarized certification of an independent laboratory, together with results of all tests, stating that these materials meet the requirements as set forth herein (section 908). These tests shall have been performed within two years of submittal. The certified test report shall state lot tested, manufacturer's name, brand name of paint and date of manufacture. The certification shall be accompanied by two one quart samples of each component. After approved by the Department, certification by the paint manufacturer shall be submitted for each batch used. New certified test results and samples for testing by the Department shall be submitted any time the manufacturing process or paint formulation is changed. This shall not constitute a waiver on the part of the Department of any requirements with respect to samples and samplings, and the right is retained to perform any or all of the tests specified. All costs of testing (other than tests conducted by the Department) shall be born by the Manufacturer.

CONSTRUCTION REQUIREMENTS

619.03 General Requirements. Except as modified herein or in contract, all surfaces to be painted shall receive Paint System No. 1. [Anchor profile and film thicknesses other than those specified will result in possible rejection or

payment adjustment per section 619.06.] Only cleaning, surface preparation and primer application should be accomplished for shop painted steel, unless otherwise specified.

The following items apply to shop and field painting as appropriate unless modified in sections 619.04 and 619.05 below.

(a) Cleaning and Surface Preparation. The surfaces to be painted and the tops of pier and abutment caps shall be washed and free of foreign matter prior to solvent cleaning. [The washing shall be completed no more than two weeks prior to surface preparation by the specified method. As directed by the Engineer,] Washing shall be completed on surfaces to receive second or third coats when foreign matter has accumulated on previously painted surfaces. Washing shall be accomplished [by using low pressure power, minimum 400 psi, water washing] using potable water or water meeting the requirements of Section 912.01. If detergents or other additives are added to the water, the surface shall be rinsed with potable water before the detergent water dries. All surfaces to be painted shall be completely free of all foreign matter [and will be approved by the Engineer] prior to solvent cleaning.

After washing, [has been approved by the Engineer] all traces of [asphaltic cement, oil, grease, diesel fuel deposits, and other] soluble contaminants which remain on steel surfaces to be painted shall be removed by solvent cleaning. Unless otherwise specified, the solvent shall be petroleum based aliphatic mineral spirits. [Under no circumstances shall any abrasive blasting be done to areas not approved by the Engineer.] Solvent cleaning shall conform to the Steel Structure Painting Council's (SSPC's) Surface Preparation Specifications SP 1 , Section 4, "Methods of Solvent Cleaning" and the contractor shall ensure the cleaning does not damage existing coatings which are to remain. [The solvent cleaning shall be approved by the Engineer before surface preparation is begun. Surfaces prepared by abrasive air blasting before solvent cleaning approval shall be completely solvent cleaned and reblasted with no additional compensation to the contractor.]

The surfaces to be painted shall be further prepared by one or more of the following specified methods. Prepared surfaces shall be painted before rust appears on the surface and no area shall remain unpainted overnight. [If rust appears or bare steel remains unpainted overnight, the affected area shall be reprepared at the expense of the contractor.] The contractor shall notify the Engineer twenty-four hours in advance of beginning surface preparation operations.

Method A (Complete Paint Removal). The surface preparation shall remove all rust, mill scale, foreign materials, and old paint down to bare metal. Unless otherwise specified, the surface preparation shall be accomplished in accordance with the requirements of the SSPC-SP 6 for Commercial Blast Cleaning. The surface preparation shall result in the specified blast profile. If rust or corrosion products have formed between connected plates or shapes of structural steel, the gap between the connected parts shall be cleaned by air blasting, hand tools or power hand tools [approved by the Engineer.] If the surface preparation results in nicks or gouges, the work will be suspended. The contractor shall demonstrate that he has made the necessary adjustments to prevent a reoccurrence of the damage [and the contractor shall be notified in writing prior to resuming work.]

Method B (Partial Paint Removal). The surface preparation shall remove all rust, loose mill scale and loose, checked, alligatored and peeling paint. Unless otherwise specified, the surface preparation shall be accomplished in accordance with the requirements of the SSPC-SP 7 for Brush-Off Blast Cleaning. In addition, visible areas of rust which remain after the brush-off blast cleaning shall be prepared to bare metal in

accordance with Method A above. An area [of a minimum of one and one half inches] between the brush off area and the removal area shall be feathered [using an approved sander] to provide a smooth transition between the new and old coatings.

Method C (Spot Paint Removal). The surface preparation shall remove all rust, mill scale and loose, checked, alligatored and peeling paint from those areas designated by the Engineer. Unless otherwise specified, the surface preparation in these areas shall be accomplished in accordance with the requirements of SSPC-SP6 for Commercial Blast Cleaning. Unless otherwise specified, the surface preparation in these areas shall result in the specified blast profile as determined by the Engineer. The contractor shall be careful not to damage sound paint adjacent to spot paint removal areas by his abrasive blasting operations. Sound paint that cannot be lifted with dull putty knife shall not be damaged or removed. The sound paint in an area [of a minimum of one and one half inches] around the commercial blast area shall be feathered [using an approved sander] to provide a smooth transition between the new and old coatings.

Method D (Spot Paint Removal). The surface preparation shall remove all loose rust, loose mill scale, and loose, checked, alligatored and peeling paint from those areas designated by the Engineer. It is not intended that adherent mill scale, rest, and paint be removed by this process. Mill scale, rust, and paint are considered adherent if they cannot be removed by lifting with a dull putty knife. Surface preparation shall be accomplished by the use of hand held tools [or other effective means meeting the approval of the Engineer.] per SSPC-SP 2. Abrasive air blasting or power tools may be used with the written permission of the engineer provided results are equal to the best results obtainable by hand methods.

Method E (new structural steel). The surface preparation shall remove all rust, mill scale and foreign materials. Unless otherwise specified, the surface preparation shall be accomplished in accordance with the requirements of the SSPC-SP 10 for Near-White Blast Cleaning.

Abrasives shall not be oil contaminated and shall have a water extract pH value within the range of 6 to 8. The abrasive supplier should perform appropriate tests at regular intervals, as agreed to with INDOT, to verify this. [All surfaces prepared with abrasives which are oil contaminated or have a Ph outside the specified range shall be cleaned with solvent cleaner or low pressure water as directed by the Engineer and reblasted by the contractor at his expense.]

After [Regardless of method of] cleaning [specified], all loose [abrasives, paint, and residue] matter shall be removed from steel surfaces and the tops of abutment and pier caps with a vacuum system or by double blowing. Double blowing shall consist of two completely separate passes of the prepared surfaces and caps. [If the double blowing method is used, the top of the horizontal surfaces shall be cleaned of any debris left by the double blowing operations.] The air from blowing nozzles will be tested for cleanliness prior to the double blowing operation per ASTM D4285. [Surfaces cleaned with blowing air not tested or approved by the Engineer shall be considered unacceptable in accordance with article 105.03 of the Standard Specifications and complete solvent cleaning of these areas will be required at the contractor's expense.]

[Painted surfaces damaged by washing, inclusion of blast residue, direct abrasive blasting, or any contractor's operation shall be removed and repainted, as directed by the Engineer, at the contractor's expense.]

Surface preparation and surface residue removal will be approved prior to painting. [Painting applied to surfaces not tested or approved by the Engineer will be considered unacceptable in accordance with Article 105.13 of the Standard

Specifications and complete paint removal shall be accomplished at the contractor's expense.]

Surface Preparation Visual Standards. [Surface preparation approval shall require the preparation of test sections.] The contractor shall prepare the surface to the specified level in accordance with SSPC Vis 1-89 standards [supplied by the Engineer.] [These visual standards shall be used to determine the degree of conformance with the appearance requirements of the prepared surface. Prior to production surface preparation the contractor shall prepare a test section on each structure to be painted in a location which the Engineer considers to be representative of the existing surface condition and steel type for the structure as a whole. The test section shall be prepared using the same equipment, materials, and procedures as the production surface preparation. The test section shall be in the range of nine to twelve square feet. Only after a test section area has been approved shall the contractor proceed with surface preparation operations. The visual standards shall be used in addition to the plans and specifications to determine acceptance of surface preparation. No additional compensation will be allowed the contractor for preparation of test sections.]

(b) Painting. Painting shall be accomplished in accordance with these specifications and [as specified] in the paint manufacturer's written instructions and product data sheets for the paint system used. The manufacturers written instructions and the paint batch certification shall be supplied to the Engineer at or before the preconstruction conference.

Thinning may be done per the manufacturer's written instructions unless otherwise specified herein. [Any plans for thinning should be submitted to the Engineer at the preconstruction conference.]
[The paint shall be power mixed in a manner which will break up all lumps, completely disperse pigment and result in a uniform composition. Paint shall be carefully examined after mixing for uniformity and to verify that no unmixed pigment remains on the bottom of the container.] Excessive skinning or partial hardening due to improper or prolonged storage will be cause for rejection of the paint even though it may have been previously inspected and accepted. Paint shall not remain in spray pots, painters' buckets, etc. overnight. Paint shall be stored in a covered container and remixed before use.

Each coat of paint shall be applied as a continuous film of uniform thickness free of pores. Each coat of paint shall be in a proper state of cure before the application of the succeeding coat. Paint shall be considered dry for recoating when an additional coat can be applied without the development of film irregularities, such as, lifting, wrinkling, or loss of adhesion of the under coat. The time interval between coating applications shall be in compliance with the paint manufacturer's instructions. If surfaces are contaminated, washing shall be accomplished prior to intermediate and final coats per the previous guidelines for washing.

Primer will be applied before rusting and blasted steel shall not remain unpainted overnight.

[Painting shall be done in a neat and workmanlike manner.] Paint may be applied with spray methods, rollers, or brushes. [If applied with conventional or airless spray methods, paint shall be applied in a uniform layer with overlapping at the edges of the spray pattern. During application, the gun shall be held perpendicular to the surface and at a distance which will ensure that a wet layer of paint is deposited on the surface. The trigger of the gun should be released at the end of each stroke. All runs and sags shall be brushed out immediately. When air spray application is used the atomizing air pressure at the gun shall be high enough to properly atomize the paint, but not so high as to cause excessive fogging of paint, excessive evaporation of solvent or loss by over

spray. When airless spray application is used the paint pressure to the gun shall be in accordance with the paint manufacturer's recommendations. Brushes shall be round or oval, except flat brushes may be used if they do not exceed four inches in width.]

If a new concrete deck is required, painting shall be done after the deck is placed and the forms have been removed.

Special Cleaning and Painting Methods. Special cleaning methods may be required to meet the cleaning requirements where special areas exist on a bridge such as ornamental handrails, lattice work, difficult to access areas, or other such appurtenances. These special methods may include hand work and the price of this should be included in the original proposal. This work will not be paid for separately.

The profile and paint system for these areas will be specified by the Engineer. [These areas shall then be primed in accordance with painting system No. 2, regardless of the system being used on other parts. No zinc coating shall be applied to areas where a blast cleaned surface in accordance with Method A has not been attained.]

[In these special areas, the finish coating of the painting system specified may be used for the structure.]

[Where surfaces have been painted with the full paint system but the paint coating has been damaged, the damaged areas shall be scraped to soundly bonded paint, and the primer and finish coats shall be re-applied. No additional payment will be made for repairing damaged areas.]

Paint Systems. The dry film thickness will be measured with a calibrated dry film thickness gauge. [No payment will be allowed for any film thickness in excess of the required minimums. No claim whatsoever shall be made arising out of any paint used in excess of the minimums required by this contract or for the stoppage of work due to a dispute of the calibration of the thickness gauge.]

1. Paint System No. 1. This system shall consist of one coat of inorganic zinc silicate primer with a minimum dry film thickness of 2.5 mils and one coat of vinyl finish paint with a minimum dry film thickness of 3.0 mils. The surface shall be prepared in accordance with Method A. The blast cleaning shall result in an anchor profile of 1-2.5 mils. In addition, the outside surface areas of all outside beams and the shoe assemblies under all expansion joints shall be given a second vinyl finish coat with a minimum dry film thickness of 2.5 mils. Total dry film thickness for these areas shall be at least 8.0 mils.

* <u>2. Paint System No. 2. This system shall consist of one coat of brownish orange shop paint, a brown first field coat, and a green finish coat.</u>

<u>All surfaces to be painted with paint system No. 2 shall be prepared using Method A with a resulting profile of 1-2.5 mils. They should receive one coat of brownish orange shop paint with a minimum dry film thickness of 2.0 mils, and then a brown first field coat with a minimum dry film thickness of 3.2 mils. The final coat shall be a green finish coat with a minimum dry film thickness of 3.0 mils. The minimum dry film thickness for both coats shall be 5 mils.</u>

3. Paint System No. 3 (Lead and Chromate Free Alkyd Paint System).

(a) Number of Coats and Minimum Thickness. When the surface is prepared using Method A or B painting, shall consist of the application of one

complete coat each of the specified primer, intermediate, and final coats. Surface preparation to bare metal shall result in 1-3.0 mil blast profile.

When the surface is prepared using Method C or D the structural steel shall be spot painted. Spot painting shall consist of the application of one coat of the specified primer on all areas where the old paint has been removed, feathered and/or damaged prior to, during or after the cleaning and surface preparation operations. On surfaces where small areas of steel at closely spaced intervals are exposed, the spot prime painting shall consist of a complete coating of the surface. Spot painting shall include a coat of the specified intermediate coat over all areas coated with the specified prime paint and over any badly stained or discolored areas of the old paint prior to the application of the complete coat of finish paint.

The minimum dry film thickness of the prime coat shall be 2.0 mils. The maximum dry film thickness of the prime coat shall be 3.0 mils. [The average wet film thickness of each coat over previously applied paint shall be 3.0 mils, but not greater than 4.5 mils.]

All shop and field contact surfaces shall not be painted, except for a mist coat on the top flange to prevent rust staining.

Field painting of all new structural steel shall consist of spot painting and application of the additional coatings required. The spot painting shall consist of the application of one coat of paint primer applied on the heads of field bolts, pins, field welds and all areas where the paint has been removed and damaged. [Spot painting shall be done as soon as the cleaning operations will permit and as far as possible in advance of the intermediate coat, but not until the cleaning is far enough ahead to eliminate danger of dirt or other material from the cleaning operations falling or blowing on the spot coat.]

(b) Application. The Alkyd coats shall be applied [by spray, brush or roller] in accordance with the paint manufacturer's printed instructions. Thinning will be considered unacceptable [and thinned coatings shall be removed at the Contractor's expense.] In cool weather the paint may be warmed to reduce the viscosity, if necessary. [Such warming shall be done by heating the paint containers in water or by other approved indirect methods.] The paint shall not be applied when the ambient temperature is expected to drop below the manufacturer's minimum application temperature within 72 hours of application of the paint.

The intermediate coat shall not be applied until the entire structure has been primed and the final finish coat shall not be applied until he entire structure has received the intermediate coat[, except with written permission of the Engineer.]

4. Paint System No. 4 (Zinc-Silicate Primer and Vinyl Paint System). The surface preparation shall be as specified for Method A, except to SSPC-SP 10 (Near White Blast Cleaning) and shall result in a 1-2.5 mil blast profile. Painting shall conform to the following requirements:

(a) Number of Coats and Film Thickness. Painting shall consist of one complete coat of Zinc-Silicate Primer and one complete coat of high-build vinyl coating. A topcoat of vinyl enamel will also be required on herein specified surfaces. The prime coat shall be applied so that a dry film thickness of at least 2.5 mils is obtained. The maximum dry film thickness is 6.0 mils. One complete coat of high-build vinyl coating of sufficient thickness shall also be applied to hide the prime coat and make the total dry-film thickness of the two coats at least 6.0 mils.

If the proper dry-film thickness of a zinc-silicate prime coat is not obtained with one coat, any contaminants shall be removed, and an additional coat of primer applied [that has been thinned up to 2 quarts per gallon. The amount of thinning will depend on the desired film build, but in no case shall the total dry film thickness of the prime coat obtained exceed 6.0 mils.]

All surfaces of structural steel elements above the deck, all outside surfaces of exterior beams or girders, the bottom surface of the lower flange on exterior beams or girders, all surfaces of elements of trusses, tied arches and other similar structure types, all surfaces of exterior bearing elements and surfaces of exterior drain pipes, that are painted with the high-build vinyl paint shall receive one coat of vinyl enamel over the high-build vinyl. The dry-film thickness of the enamel coat shall be sufficient to hide the high-build vinyl finish coating and make the total dry-film thickness of the three-coat system at least 7.0 mils.

(b) Application. Paint shall not be applied when the ambient temperature is expected to drop below the manufacturers minimum application temperature before the coating has dried.

[The paint shall be thoroughly mixed before being applied and the pigments shall be kept in suspension. Zinc-Silicate primer, after initial mixing, shall be strained through a metal screen not coarser than 30 mesh or finer than 60 mesh, before application. When zinc-silicate paint is being applied, the material must be kept under constant agitation to avoid settling.]

[Paints shall be applied by either airless or conventional spray methods, except areas inaccessible to spray application may be painted by brush or daubers, and small touch-up areas may be painted by brush. When Zinc-Silicate Primer is applied by spray, a mechanically agitated pressure pot shall be used. The pressure pot and spray gun shall be approximately the same height while spraying. Application of paint shall produce a smooth, uniform coating.] Thinning will be permitted when required for proper application.

[The type of thinner used and the amount used shall be as recommended by the paint manufacturer. The paint shall be thinned for spraying to suit prevailing weather conditions so that a wet spray is provided at all times and the deposition of particles which are dry when they strike the surface is avoided. In this regard, care shall be used to insure that the spray nozzle is held close enough to the surface to avoid excessive loss of volatiles. Painting shall not be done when the steel is hot enough to cause the paint to blister or produce a porous paint film.]

[In no case shall a coat of paint be applied until the previous coat has been inspected by the Engineer and found to be dry and cured throughout the entire film thickness.] The zinc-silicate paint shall pass the MEK rub test prior to application of the high build vinyl paint.

Thinning of the vinyl coats shall satisfy the paint manufacturer's printed recommendations. [Prior to thinning, the Contractor shall supply the recommendations regarding thinning to the Engineer. Paint not thinned in accordance with the paint manufacturer's recommendations will be considered unacceptable and shall be removed and the area repainted at the Contractor's expense.]

The high-build vinyl coat shall not be applied until the entire structure has been primed, and the vinyl enamel coat shall not be applied until the entire structure has been top coated with the high-build vinyl[, except

with written permission of the Engineer.]

* 5. Paint System No. 5 (Aluminum Epoxy Mastic and Vinyl System). Surface preparation shall result in a 1-3 mil blast profile. Painting shall conform to the following requirements:

(a) Number of Coats and Film Thickness. Painting shall consist of one complete coat of aluminum epoxy mastic primer and one complete coat of high-build vinyl coating. One coat of vinyl enamel on herein specified surfaces will also be required. The aluminum epoxy mastic primer shall be applied so that a dry film thickness of at least 6 mils is obtained. The maximum dry film thickness of the aluminum epoxy at any spot shall be 10 mils. The high-build vinyl coating shall be applied so that a dry-film thickness of at least 9 mils of the two coats is obtained. The maximum dry-film thickness of the two coats at any spot shall be 15 mils.

All surfaces of structural steel elements above the deck, all outside surfaces of exterior beams or girders, the bottom surface of the lower flange on exterior beams or girders, all surfaces of elements of trusses, tied arches and other similar structure types, all surfaces of exterior bearing elements and surfaces of exterior drain pipes, that are painted with the high-build vinyl coating shall receive one coat of vinyl enamel over the high-build vinyl and make the total average dry-film thickness of the three-coat system at least 10 mils.
(b) Application. The aluminum epoxy coating shall not be applied when the surface temperature is below 50 degrees F and shall not be applied when the ambient temperature is expected to drop below the manufacturer's minimum application temperature before the coating has cured. Curing times at various temperatures shall be provided by the paint manufacturer.

[The aluminum epoxy mastic shall be applied by spray, brush or roller in accordance with the paint manufacturer's printed instructions.] Thinning for spray application of the aluminum epoxy shall be in accordance with the manufacturer's instructions. [If brushes and/or rollers are used two applications shall be required to obtain the average 6.0 mils dry film thickness allowing the minimum time recommended by the manufacturer between applications.] The maximum combined thickness of the two applications shall be 14.0 mils. The first applications shall be tinted to produce a distinct contrast with the second application. When topcoats are applied, the recommendations of the aluminum epoxy mastic manufacturer shall be followed as to surface preparation on the aluminum epoxy mastic. In humid weather, a surface exudate may form which must be washed off with clean and potable water to obtain topcoat adhesion.

Thinning of the vinyl coats shall satisfy the paint manufacturer's printed recommendations. [Prior to thinning, the Contractor shall supply the recommendations regarding thinning to the Engineer. Paint not thinned in accordance with the paint manufacturer's recommendations will be considered unacceptable and shall be removed and the area repainted at the Contractor's expense. If a paint coating is too thin or if portions of the steel are not coated completely, such portions of the work shall be corrected as directed by the Engineer.]

[The "Aluminum Epoxy Mastic Primer" shall be top coated with the high-build vinyl and the vinyl enamel during the period recommended by the paint manufacturer].

Special Instructions for All Paint Systems. [After cleaning, the surfaces to be painted shall remain free of moisture and other contaminants. The contractor shall control his operations to insure dust, dirt or moisture does not come in contact with surfaces cleaned or painted while they are drying.]

Removal of Unsatisfactory Paint. If the paint coat wrinkles or shows evidence of having been applied under unfavorable conditions, or if the workmanship is poor, the Engineer may order it removed and the steel cleaned and repainted at the Contractor's expense. All areas where "mud cracking" occurs [in a film of Aluminum Epoxy Mastic, or Zinc-Silicate Primer] shall be scraped back to soundly bonded paint and recoated at the Contractor's expense. [All areas where the paint film exceeds the maximum thickness shall be corrected by the Contractor at his expense using methods approved by the Engineer. If the dried paint coating is too thin or if portions of the steel are not coated completely, such portions of the work shall be corrected as directed by the Engineer.]

[Recoatability. Additional coats shall be added per the manufacturer's specifications.]

Marking. Except for marks required for erection, no lettering of any type shall be painted on bare or painted structural steel, except after the finish coat is approved, the following shall be painted with a stencil in 2 inch black letters: PAINTED - contract number - date. This shall be placed on the outside of a facia beam near the end bent, or at some equally visible surface near the end of the bridge as designated by the Engineer.

[Cleanup. All surfaces painted inadvertently shall be cleaned immediately.]

Responsibility for Damage. All persons and property shall be protected from damage or injury from the paint, painting operations, and blast cleaning operations. [Persons and property shall include, but shall not be limited to, pedestrians, vehicular and other traffic upon or underneath bridges, all portions of the bridge superstructure and substructure, and all adjacent property.] The Contractor shall be responsible for damages in accordance with 107.14.

(c) Inspection.

INSERT STATISTICAL ACCEPTANCE/ADJUSTABLE PAYMENT INFO.

Inspection. The work shall progress across the structure in an organized fashion. A plan for the work progress at each structure will be submitted to the Engineer at the preconstruction conference.

[When complete paint removal is specified,] the average surface profile will be determined [at the beginning of the work and as required by the Engineer] using a profile depth tape and/or micrometer. Single measurements less than 1 mil, or greater than the specified maximum for the painting system used will be considered unacceptable. [Areas having unacceptable measurements will be further tested to determine the limits of the deficient area. When unacceptable profiles are provided, work will be suspended or an adjusted payment will be determined. The contractor shall submit a plan for the necessary adjustments to insure the correct surface profile on all surfaces and the contractor shall be notified in writing by the Engineer prior to resuming work.]

The procedures used to calibrate and use the dry film thickness gauges of the paint will conform to SSPC-PA 2. When the dry film thickness does not satisfy the specified film thickness the contractor shall apply an additional paint coat over the entire area to a thickness as required.

[The contractor is encouraged to measure the wet film thicknesses with approved wet film thickness gauges. If the measurements are taken at sufficient frequency during paint application, adjustments can be made before the paint dries.

Inspection Facilities. In addition to the requirements of article 105.10, the contractor shall furnish, erect and move scaffolding or other mechanical equipment to permit inspection and close observation of all surfaces cleaned, prepared and painted. This equipment shall be provided during all phases of the work. The contractor shall submit a plan for providing inspection access at or before the preconstruction conference.

When the surface to be inspected is more than fifteen feet above the ground or water, the contractor shall provide the inspector with a safety belt and a lifeline. The lifeline shall not allow a fall greater than six feet, nor shall the lifeline and attachment direct the fall into oncoming traffic. The contractor shall provide a method of attaching the lifeline to the structure independent of the inspection facility or any support of the platform. When the inspection facility is more than two and one half feet above the ground the contractor shall provide an approved means of access onto the platform.

Work performed without adequate provision for inspection will be considered unacceptable in accordance with article 105.11.

Unsatisfactory Work. Blast work or paint work, [at any stage of its completion,] which is determined to be unsatisfactory shall be cleaned, prepared again and repainted [as directed or an adjustable payment will be determined.]

(d) Weather Conditions. Cleaning and painting shall be accomplished only when the following conditions, or more restrictive conditions specified in the manufacturer's written instructions for the paint system used, have been met.

The minimum temperature of the air shall be 40 degrees F and the steel shall be 50 degrees F, unless otherwise specified. Coatings shall not be applied to surfaces hotter than 130 degrees F or when the temperature exceeds 100 degrees F.

The surface temperature shall be at least 5 degrees F above the dewpoint of the air surrounding the surface. In addition, the relative humidity of this air shall be less than 85%, except for zinc-silicate primer in which case it should be also above 50% to allow proper moisture for curing.

Spray painting shall not be permitted when wind velocities are greater than 15 mph.

[These conditions will be determined by the Engineer at locations representative of the surfaces to be cleaned and painted. Work accomplished under unfavorable weather conditions will be considered unacceptable in accordance with article 105.11 and complete recleaning and repainting of these areas will be required at the contractor's expense.]

(e) Equipment. All cleaning and painting equipment shall include gauges recommended by the equipment manufacturer capable of accurately measuring fluid and air pressures and shall have valves recommended by the equipment manufacturer capable of regulating the flow of air, water, abrasive material or paint.

[Pressure type abrasive air blasting equipment shall be capable of supplying a minimum of 100 psi pressure and 250 cfm capacity with all air blast nozzles being used. If blast nozzle orifice sizes larger than 3/8" are being used, the minimum capacity of the equipment shall be increased in accordance with the recommendations of the Steel Structures Painting Council's (SSPC) Good Painting Practice, Volume 1, Chapter 2.4, Table 1. The pressure will be measured at the blast nozzle.] The equipment shall be capable of providing [the minimum] required pressure and volume, free of oil, water and other contaminants.

Spray painting and cleaning equipment shall utilize filters, traps or separators

recommended by the manufacturer [of the equipment and shall be kept clean to prevent oil, water, dried paint and other foreign materials from being deposited on the surface. The filters, traps and separators shall be cleaned or drained as recommended by the manufacturer of the equipment at intervals recommended by the manufacturer.] Airspray paint pots shall be equipped with air operated continuous mixing devices.

Prior to beginning all cleaning and painting operations, air equipment shall pass the requirements of ASTM D 4285. [This test will be repeated as determined by the Engineer.]

(f) Traffic Provisions. Traffic shall be permitted to use the roadway of these structures at all times, two lane traffic being maintained where at all possible. The roadway shall be restricted to one lane traffic when blast cleaning or painting a portion of a structure that is over the traveled roadway, or when it is determined that the need exists.

While actual work is being performed on a through truss span, one-half the roadway on that span may be closed to traffic at the option of the contractor. One-way traffic shall be permitted over the other half of the roadway if the bridge roadway is less than 40 feet in width. Two- way traffic shall be permitted over the other half of the roadway if the bridge roadway is 40 feet or more between curbs.
When sidewalk railings are painted, such portion of the sidewalk as approved by the Engineer may be closed to pedestrian traffic until the paint is dry; but wherever possible, a portion of the sidewalk width shall remain open to pedestrian traffic at all times.

During blast cleaning operations, the contractor shall make provisions to protect existing traffic from any hazards resulting from the blast cleaning operations. [The provisions shall include a type of barrier system which would protect against direct blasting of vehicles or pedestrians, eliminate abrasive materials and debris from falling on the traveled portions of the pavement, and prevent the spreading of abrasive materials and debris in the area which would create a traffic hazard.] A plan detailing the method of protection to be used shall be submitted.

Whenever the intended purpose of the protective devices is not accomplished, work shall be suspended until adequate corrections are made. In addition, any abrasive material and debris deposited on the pavement and shoulders in the working area shall be removed.

(g) Prosecution of work. Prosecution of work shall be in accordance with applicable provisions of 108.03. Once the operation of cleaning and painting is begun, it shall be prosecuted on all acceptable working days without stoppage, until all work is completed, including all clean up. Contractor shall submit a proposed schedule at the preconstruction conference to indicate the sequence in which the various structures are to be painted, when more than one is included in the contract. [This will be reviewed and approved by the Engineer prior to work.]

619.04 Shop Painting. All structural steel included in contracts which involve erection shall receive an inorganic zinc silicate primer, including contact surfaces of high-strength bolted connections and areas in contact with concrete, unless otherwise specified herein or in the contract. Where shear connectors are used, the top of the flange shall be painted after connectors have been welded on to prevent rust staining.

Surfaces other than contact surfaces referred to above, which are inaccessible after erection, shall be painted in the shop with the full paint system required on the completed structure.

Machine finished surfaces for sliding contact shall be coated as soon as practicable after being accepted, but before removal from the shop, with a hot mixture of 4 pounds of tallow, [2 pounds of white lead,] and one quart of linseed oil, or with heavy grease.

Erection marks shall not be painted on bare steel surfaces. Shop painted material shall not be loaded for shipment until the paint is dry.

The top flange of shop painted steel shall be given a mist coat of primer to prevent rusting and staining while in storage.

619.05 Field Painting. Field painting will not be permitted between November 15 and April 1.

(a) New Construction. All structural steel that has received inorganic zinc silicate primer, except contact surfaces or surfaces to be in contact with concrete, shall be painted after erection with the vinyl finish coat of Paint System No. 1 unless otherwise specified. When the specifications do not permit the material to receive an inorganic zinc silicate primer in the shop before incorporation into the structure, the surfaces which are exposed shall be cleaned in accordance with 619.03 Method E before any paint is applied and shall receive the inorganic zinc silicate primer after erection.

Before application of the vinyl finish coat, all areas where the inorganic silicate primer was damaged during shipping, handling, and erection, and all bolts and field connections shall be cleaned in accordance with 619.03 Method C and painted with primer to a condition equal to that applied in the shop.

Where surfaces have been painted with the full paint system but the paint coating has been damaged, the damaged areas shall be scraped back to soundly bonded paint, and both the inorganic zinc silicate primer and the vinyl finish coat reapplied.

[Concrete at all junction points of concrete and steel shall be adequately shielded or otherwise protected so that application of paint on steel is full and complete, and spraying on the concrete is minimized.]

All members inaccessible to field painting after being placed in final position shall have been given the vinyl finish coat before being erected.

After completion of the vinyl finish coat, the cover plates of end posts and the
* ends of plate girders at each end of the bridge shall be painted with 8 inch alternate stripes sloping down at an angle of 45 degrees, toward the side on which traffic passes. The stripes shall be white codit reflective or equal and black field paint. The striping shall extend from the floor level to the connection point of the cross-portal member, or the top of the chord, or to a point 12 feet above the bridge floor, whichever is lowest.

If there is a steel railing, the roadway face shall be given one coat of white field paint.

(b) Cleaning and Painting Old Steel Bridges. The surfaces to be cleaned and painted shall include all steel work, including iron or steel castings and steel railing, that have been previously painted or are accessible for field painting, unless otherwise provided. Tops of expansion guard plates or angles across the roadway at joints between adjacent spans on which traffic comes in direct contact, the top of top flanges of stringers and girders to be reimbedded in concrete, or pipe and ducts owned by utility companies, will not require painting.

General Requirements. Any plans that may be furnished for the work, and any dimensions, weight of steel or other information given regarding a bridge, are

only for the purpose of assisting bidders in determining the type and amount of steel to be cleaned and painted. It is the responsibility of the contractor to verify this information and the information provided shall in no way affect the lump sum price bid for cleaning and painting the bridge.

A aatisfactory Progress Schedule showing the sequence for cleaning and painting each bridge, shall be submitted to the Engineer on or before the preconstruction conference. [If the Contractor fails to comply with the schedule or requirements for revisions to the schedule, work will be suspended.]

Proposed inspection access provisions shall be submitted to the Engineer on or before the preconstruction conference. Proposed inspection access shall be approved by the Engineer for each structure prior to beginning of work.

Striping End Posts. Upon completion of the finish coat, the end batter posts of trusses and the roadway face of steel railing shall be painted with stripes in accordance with 619.05(a).

Pollution Control. Paint particles resulting from cleaning and blasting operations over waterways shall be retained. The use of booms and skimmers shall be employed in order to prevent any paint particles from floating downstream from the painting, cleaning, and blasting operations. The contained material shall be removed from the water prior to settling. No waste material is to remain on the booms or water surface overnight. An alternate method may be used provided it can be shown to be effective.

All waste material is to be properly stored at the site to prevent loss or pollution and subsequently disposed of at a disposal site approved by the Solid Waste Management Section of the Indiana State Board of Health. A letter of authorization shall be obtained from the Solid Waste Management Section for specific site upon providing the Section with type of liquid or dry material contents, and approximate amount. The authorization shall be obtained prior to starting work. All measures and precautions necessary to ensure the proper function of these controls shall be taken. Blasting and cleaning in the vicinity of the stream shall not be performed on days when the wind is of such velocity to prevent the retention of the paint particles.

619.06 Payment.

INSERT STATISTICAL ACCEPTANCE/ADJUSTABLE PAYMENT INFO

Method of Measurement. No measurement will be made for painting, except old steel bridges or other specific items, unless so specified or set out in the proposal. It is understood and agreed that the cost of all work outlined above, unless otherwise specified, has been included in the bid, and no extra compensation will be allowed.

Basis of Payment. Painting will not be paid for separately unless so specified, but the cost thereof shall be included in the cost of pay items.

If the contract includes an item for maintaining traffic, then the contract lump sum price bid for each structure will be payment in full for furnishing all the labor, materials, and equipment required to maintain traffic.

Pollution control devices required when cleaning and painting old steel bridges will be paid for at the lump sum price bid for pollution control, which payment shall be full compensation for all equipment, material, and labor necessary to provide this item, including disposal of spent materials. [No additional compensation whatsoever will be made for delays from any operation undertaken under this item.] The absence of a pollution control item does not negate the Contractor's responsibility for complying with the pollution control requirements

in all phases of this work.

The accepted quantities of old steel bridges and/or specific items to be painted will be paid for at the contract unit price per each or in one lump sum, as set out in the proposal. The unit or lump sum price shall be full compensation for labor, equipment, tools, and incidentals necessary to complete the items.

Payment will be made under:

Pay Item	Pay Unit
Cleaning (Old Steel Bridge)	Lump Sum, Each
Painting (Old Steel Bridge)	Lump Sum, Each
Maintaining Traffic (Old Steel Bridge) . .	Lump Sum, Each
Pollution Control (Old Steel Bridge) . . .	Lump Sum, Each
Painting ____________________ . . . . . . (specific item)	Lump Sum, Each

SECTION 908 - PAINT AND LIQUID EPOXY

Aluminum Epoxy Mastic Primer

The material for aluminum epoxy mastic primer shall conform to the following requirements:

The aluminum epoxy mastic primer shall be a two component epoxy containing aluminum pigment. The aluminum epoxy mastic shall be designed as a one coat high-build complete protective coating system with excellent adhesion to rusted steel, inorganic zinc and old paint after such surfaces have been properly cleaned. The aluminum epoxy mastic shall be compatible with a wide range of topcoats including the vinyl paints specified in Article 712.26 of the Standard Specifications for Road & Bridge Construction.

(1) Pigment - The primary pigment shall be either a leafing or non-leafing aluminum pigment. Secondary pigmentation shall contain no toxic heavy metals.

(2) Vehicle - The vehicle shall be a modified epoxy and curing agent which is suitable insensitive to moisture to allow trouble free application.

(3) Packaged Components - The epoxy coating shall be supplied as a two-component material at a one-to-one volume mix ratio. It shall be well ground, free of caking, skins, gelatin and excessive settling. The shelf life of each component shall be no less than twelve months.

(4) PROPERTIES OF ALUMINUM EPOXY MASTIC

a. The mixed epoxy shall contain a minimum of 90 percent solids by weight, when tested according to ASTM D 1644, Method A, except that the sample shall be heated for 72 hours at 100 degrees + or - 2 degrees F.

b. The weight per gallon of the unmixed components shall not vary more than + or - 0.2 pounds from the weight of the original qualification samples.

c. The viscosity of the coating shall be a minimum of 95 KU at 77 degrees + or - 2 degrees F. Viscosity must be checked immediately after addition and mixing of components.

d. The pot life of the epoxy coating shall be no shorter than 2 hours at 75 degrees F. or one hour at 90 degrees F.

e. The epoxy coating shall air cure at a temperature of 75 degrees F. or above to a hard tough film within 5 days by evaporation of solvent and chemical reaction. It shall be dry to the touch in 24 hours at 75 degrees F., and to receive foot traffic in 48 hours at 75 degrees F.

f. The mixture, when thinned per manufacturer's recommendations, shall exhibit no runs or sags, when applied by conventional or airless spray to produce dry film thicknesses in the 5 to 7 mil range.

(5) Resistance Tests of Cured Aluminum Epoxy Mastic - Test panels of steel meeting the requirements of ASTM D 609, having dimensions of 2 X 5 inches X 1/8 inch thick, shall be prepare by sandblasting all surfaces to a white metal finish in accordance with Structural Steel Painting Council SP5 (SSPC-SP5). The cleaned panels shall then be exposed to outdoor weather for 30 days or until uniform rusting occurs. They shall then be hand cleaned with a wire brush in accordance with SSPC-SP2. A 6 mil dry coating of the epoxy mastic shall then be applied in one coat in accordance with the manufacturer's current printed instructions. The

coating shall be cured as recommended by the manufacturer. Each of the following tests shall be performed on one or more test panels. Test panels that must be scribed shall be prepared according to the requirements in ASTM D 1654. The material will not be accepted if any individual test panel fails any of the following tests:

(a) Fresh Water Resistance. Panels shall be scribed down to base metal with an X of at least 2 inch legs and shall be immersed in fresh tap water at 75 + or - 5 degrees F. The panels shall show no rusting, blistering, or softening beyond 1/16 inch from the scribe mark, when examined after 30 days. Discoloration of the coating will be allowed.

(b) Salt Water Resistance. Panels shall be scribed down to base metal with an X of at least 2 inch legs and immersed in 5 percent sodium chloride at 75 + or - 5 degrees F. The panels shall show no rusting, blistering or softening beyond 1/16 inch from the scribe mark upon examination after 7, 14 and 30 days. Discoloration of the coating will be allowed. The sodium chloride solution shall be replaced with fresh solution after each examination.

(c) Salt Fog Resistance. Panels shall be scribed down to base metal with an X of at least 2 inch legs. The panels shall then be tested in accordance with ASTM B 117. After 1,000 hours of continuous exposure, the coating shall show no loss of bond, nor shall it show rusting or blistering beyond 1/16 inch from the center of the scribed mark.

(d) Weathering Resistance. Panels shall be tested in accelerated weathering using either the light and water exposure apparatus (fluorescent UV-condensation type) as specified in ASTM G-53 for 1000 hours with a cycle consisting of eight hours UV exposure at 60 degrees C followed by four hours of condensation at 40 degrees C or the weatherometer in accordance with ASTM G-23, Type D for 1000 hours beginning the test at the start of the wet cycle. After this period, the panels shall show no loss of bond, nor shall it show rusting, softening or blistering.

(6) Packaging and Labeling - The aluminum epoxy mastic coating shall be packaged in two containers. The components shall be prepackaged such that mixing on a one-to-one ratio, by volume, utilizes a complete container of each component.

Each container shall be a label on which shall be clearly shown the manufacturer and brand name of paint, the lot number, the date of manufacturer and shelf life. The label on the vehicle container shall also include complete instructions for the use of this paint. The container shall be coated, if necessary, to prevent attack by the paint components.
Certification: Prior to approval and use of the aluminum epoxy mastic, the manufacturer shall submit a notarized certification of an independent laboratory, together with results of all tests, stating that these materials meet the requirements as set forth herein. These tests shall have been performed within two years of submittal. The certified test report shall state lot tested, manufacturer's name, brand name of paint and date of manufacture. The certification shall be accompanied by two one quart samples of each component. After approved by the Department, certification by the paint manufacturer shall be submitted for each batch used. New certified test results and samples for testing by the Department shall be submitted any time the manufacturing process or paint formulation is changed. This shall not constitute a waiver on the part of the Department of any requirements with respect to samples and samplings, and the right is retained to perform any or all of the tests specified. All costs of testing (other than tests conducted by the Department) shall be borne by the Manufacturer. The aluminum epoxy mastic shall not be used until they have met the requirements as set forth herein.

<u>Lead and Chromate Free Alkyd Paint System</u>. These paints for shop, field and maintenance painting of structural steel shall comply with the requirements hereinafter specified.

(a) Primer. This paint shall meet the requirements of Section 4 (composition) and Section 5 (properties) of the Steel Structures Painting Council's Paint Specification No. 25 for red iron oxide, zinc oxide, raw linseed oil and alkyd primer as outlined in Volume 2, Systems and Specifications, Third Edition.

(b) Intermediate Coat. This paint shall meet the same requirements as the primer except that it shall be tinted to produce a distinct contrast with the primer.

(c) Final Finish Coat. This paint shall meet the requirements of Section 4 (composition) and Section 5 (properties) of the Steel Structures Painting Council's Paint Specification No. 21 for lead free white or colored silicone alkyd paint, Type 1, high gloss as outlined in Volume 2, Systems and Specifications, Third Edition. The color of the paint shall match the specified Munsell Color Standard within 2 Hunter Delta E Units and shall pass the following accelerated weathering test.

Accelerated Weathering - The paint shall be applied to an aluminum alloy panel (Federal Test Standard No. 141, Method 2013) with a 0.010 inch gap clearance film applicator and allowed to air dry for 168 hours. Subject the coated panel for 300 hours to accelerated weathering using the light and water exposure apparatus (fluorescent UV-condensation type) as specified in ASTM G 53. The cycle shall consist of 8 hours UV exposure at 60 degrees C followed by four hours of condensation at 40 degrees C. At the end of the exposure period the panel shall show a color change of not more than 5 Hunter Delta E Units and the 60 degrees specular gloss shall not be less than 50.

Inorganic Zinc Silicate (optional colors). See also IDOT 1988 Standard Specifications for material specifications.

The specified color shall meet the requirements in the following table:

Color Designation	Munsell Color Standard	Pigmentation*	Total Solids Minimum	Pigment Min	Pigment Max	Vehicle Solids Minimum
Interstate Green	7.5G 4/8	Titanium dioxide, nickel titanate, Phthalocynanine blue, light stable yellow (Benzimidazolone Type)	60	18	22	40
Reddish Brown	2.5YR 3/4	Red iron oxide, yellow iron oxide, titanium dioxide, carbon black or lampblack	58	14	18	42
Light Grey	10Y 7/1	Titanium dioxide, yellow iron oxide, carbon black or lampblack	58	14	18	42
Moderate Yellow	10YR 7/8	Titanium dioxide, yellow iron oxide, light stable yellow and orange (Benzimidazolone Type)	59	18	22	39
Moderate Green	7.5GY 5/4	Titanium dioxide, phthalocynanine green, phthalocynanine blue, light stable yellow and orange (Benzimidazolone Type), carbon black or lampblack	57	20	24	35
Dark Grey	10B 5/1	Titanium dioxide, yellow iron oxide, carbon black or lampblack	61	23	27	36

Color Designation	Munsell Color Standard	Pigmentation*	Total Solids Minimum	Pigment Min	Pigment Max	Vehicle Solids Minimum
Olive Yellow	2.5Y 6/6	Titanium dioxide, phthalocynanine green, light stable yellow and/or orange (Benzimidazolone Type)	56	14	18	40
Light Green	7.5GY 7/2	Titanium dioxide, phthalocynanine blue, light stable yellow (Benzimidazolone Type)	64	30	34	32
Light Olive Grey	7.5Y 5/2	Titanium dioxide, yellow iron oxide, phthalocynanine blue, light stable yellow and/or orange (Benzimidazolone Type), carbon black or lampblack	62	28	32	32
Moderate Brown	5YR 4/4	Titanium dioxide, yellow iron oxide, red iron oxide, carbon black or lampblack	56	15	19	39
Blue	10B 3/6	Phthalocynanine blue, phthalocyanine green, titanium dioxide, quinacridone violet	56	14	18	40
Pale Brown	7.5YR 4/2	Titanium dioxide, yellow iron oxide, red iron oxide, light stable orange (Benzimidazolone Type), carbon black or lampblack	61	23	27	36

*Extender pigments are not allowed.

Appendix 11-1

Summary of Proposed Inspection Checklist

for

Painting Constructions of Highway Steel Bridges

Dec. 22, 1991

1. Introduction (Dec. 22, 1991)

The major inspections of the bridge painting can generally be divided into four stages. They are (I) pre-inspection, (II) surface preparation inspection, (III) primer inspection, (IV) top-coat inspection. These step-by-step checklists have been prepared for both shop painting and field painting which are shown in Appendix 11-2 and Appendix 11-3. The detailed procedures for each stage are described below:

<u>(I) Pre-inspection stage</u> <Using Form 1-1>

In this stage, inspectors should receive and review project information. The necessary information is:

- Contract and contractors
- Contractor's application plan/schedule (for field painting)
- Bridge dimensions
- Manufacturer's instructions for the paint
- Contractor's Proposed traffic control and inspection access plan (for field painting)

Inspectors should also prepare the necessary instruments for inspection and make sure they work well. These instruments include:

- Psychrometer
- US Weather Bureau Psychometric Tables
- Surface Temperature Thermometer
- Dry Film Thickness Gage
- Testex Micrometer with X-coarse Tape
- SSPC Surface Preparation Specifications (SSPC Visual 1-89)
- NBS Calibration Standard (if banana gage used)
- Tape Measure (for stratified sampling scheme)
- Wind Speed Gage (for field painting)
- Flash Light (for visual checking)

Contractors should submit the following information to the inspectors:

- Paint application plan/schedule (for field painting)
- Paint life data & label information
- Technical data and manufacturer's instruction which includes suggested :
    - coating thickness
    - pressure of spray gun
    - distance of spray gun from the steel surface
    - proper temperature, humidity, and wind speed for application
    - method of thinning/mixing
- Traffic control plans (for field painting) and inspection access plans

(II) Surface Preparation Stage <Using Form 2-1>

This stage is before application of the primer. In this stage, the following items should be checked by the inspectors:

Surface Cleaning

The surfaces to be painted shall be washed off all dust, dirt, and salt by clean water. After washing is approved by the inspectors, all grease, asphalt shall be removed by solvent cleaning.

Air Supply (Clean Air Test)

If the air-sand blast method is used, the cleanliness of air supplied should be checked before the blasting by the method suggested by SSPC (Appendix 11-6).

Profile

Use X-coarse tape to measure the anchor profile. The measurements should be taken at various spots of the steel members so as to get a representative sample of the overall project. One day's product is treated as a lot. Within the lot, a double sampling system is applied. The parameters of the double sampling is: n1=n2=10; c1=1; r1=3; c2=4 (please see the flow chart in appendix 11-7). The Testex tape should be filed for future reference.

Surface Cleanliness

The blasted steel surface should be checked visually to quickly find out the defective area. Around the same spots where the profile measurements are taken, proper surface cleanliness grades should be checked. If the requirements are not met, rework is necessary. The correction should be approved by the inspector.

(III) Primer Inspection Stage <Using Form 3-1, 3-2>

After the profile and cleanliness inspection are approved and before the application of the top coats is the Primer Inspection Stage. In this stage, the following items are checked:

Ambient Conditions (Humidity, Air/Steel Temperature, Wind Speed and Dew Point)

In each work day, a psychrometer is required to check the humidity, temperature and dew point. A chart or table which is shown in Appendix 11-8 is needed to get the relative humidity value and dew-point. When the weather conditions do not meet the following requirements, the job should be stopped.

General Requirement:

- Humidity : 50% - 90%
- Wind Speed : <= 15 mph (for field painting only)
- Air Temperature : 40°F - 100°F
- Steel Surface Temperature : At least 5°F higher than dew points

If the manufacturer's instructions fall outside of the above specifications, the design engineer should be consulted prior to paint application.

Paint Material

The primer paint material should be sent to and verified by the INDOT laboratory for verification test before commencement of the job. The shelf and pot life of the paints should be checked and recorded. When the requirements are not met, the job should be stopped immediately. Power mixing of the paint is necessary.

Calibration

Inspectors should calibrate the dry film thickness gage by following the SSPC-PA2 calibration method (Appendix 11-5).

Air Supply (Clean Test)

The quality of the air used in blowing down or conventional spray should be checked. The cleanliness of air should be checked by the method suggested in the SSPC manual (Appendix 11-6). If the air supply does not meet the requirements, the application of the primer should be stopped immediately.

Dry Film Thickness

The inspectors need to take dry film thickness (DFT) measurements and these readings should be taken at various spots along the steel members by following the sample scheme (Appendix 11-2 & Appendix 11-4).

Time Period (between blasting & priming)

No more than 24 hours are allowed between blasting & priming.

Visual Inspection

Bubbling, Mudcraking, Pinhole and Dry Spray should be checked and corrected under the direction of inspectors.

<u>(IV) Top-Coating Checking Stage</u> <Using Form 4-1, 4-2>

The period of Top-Coating Checking Stage comes after the primer checking stage is approved and the steel members receive a top-finish coating. In this stage inspectors should check the following items:

Ambient Conditions
(Humidity, Air/Steel Temperature, Wind Speed and Dew Point)

A psychrometer is required to check the humidity, temperature and dew point. A chart or table whcih is shown in Appendix 11-8 is needed to get the relative humidity value and dew-point. When the weather conditions do not meet the following requirements, the job should be stopped.

General Requirement:

- Humidity : 50% - 90%
- Wind Speed : <= 15 mph (for field painting)
- Temperature (air) : 40°F - 100°F
- Temperature (steel surface) : At least 5°F higher than dew points

If the manufacturer's instructions fall outside of the above specifications, the design engineer should be consulted prior to paint application.

Paint Material

The primer paint material should be sent to and verified by the INDOT laboratory for verification test before commencement of the job. The shelf and pot life of the paints should be checked and recorded. When the requirements are not met, the job should be stopped immediately. Power mixing of the paint is necessary.

Calibration

Inspectors should calibrate the dry film thickness gage by following the SSPC-PA2 calibration method (Appendix 11-5).

Air Supply (Clean Test)

The quality of the air used in blowing down or conventional spray should be checked. The cleanliness of air should be checked by the method suggested in the SSPC manual (Appendix 11-6). If the air supply does not meet the requirements, the application of the primer should be stopped immediately.

Dry Film Thickness

The inspectors need to take dry film thickness (DFT) measurements and these readings should be taken at various spots along the steel members by following the sample scheme (Appendix 11-3 and Appendix 11-4).

Visual Inspection

Bubbling, Mudcraking, Pinhole and Dry Spray should be checked and corrected under the direction of inspectors.

Appendix 11-2

Shop Painting Inspection Forms

(Dec. 22, 1991)

INSPECTION CHECKLIST FOR SHOP PAINTING Form 1-1

Stage-I (Pre-Inspection) Date ______________

Inspected by ______________

Report No. ______________ Contract ______________

Fabricator ______________ Project ______________

Fabricator's Job No. ______________ Structure ______________

1. Is the contract of the project reviewed? .... Yes No
2. Does the fabricator submit the paint manufacture instructions? .... Yes No
3. Is following equipments ready to use?
   - Psychrometer .... Yes No
   - US Weather Bureau Psychometric Tables .... Yes No
   - Surface Temperature Thermometer .... Yes No
   - Dry Film Thickness Gage .... Yes No
   - Testex Micrometer with X-coarse Tape .... Yes No
   - SSPC Surface preparation Specifications (SSPC 1-89) Yes No
   - Tape Measure .... Yes No
   - Flash Light .... Yes No

INSPECTION CHECKLIST FOR SHOP PAINTING Form 2-1

Stage-II (Surface Preparation Inspection)

Date____________

Inspected by ____________

Report No. ________________ Contract ________________

Fabricator ____________________ Project ________________

Fabricator's Job No. ______________ Structure ________________

Air Cleanliness .... Yes No.

Required Profile (mil):________________

Required Surface Cleanliness Grade:____________________

Cleanliness of Steel Surface before Painting

(Please Check With a White Napkin) .... Yes No

Daily Working Report for Profile Measurement

<<First Sampling>>

	Location Beam No.	Profile Reading (mils)	Time/Date of Sand Blast	Visual Cleanliness Checking SSPC Grade of Steel Surface
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

Number of Defect (x1=): ______

If $(x1 \leq 1)$ then Accept

If $(x1 = 2)$ Take Second Sampling

If $(x1 \geq 3)$ Reject

<<Second Sampling>>

11				
12				
13				
14				
15				
16				
17				
18				
19				
20				

Number of Defect (x2=):____ Total Number of Defect (x1+x2=)____

If $(x1+x2 \leq 4)$ then Accept

If $(x1+x2 > 4)$ Reject

INSPECTION CHECKLIST FOR SHOP PAINTING
Stage-III (Primer Inspection)

Form 3-1

Date ______________

Inspected by ____________

Report No. ____________ Contract ________________

Fabricator _____________ Project _________________

Fabricator's Job No. _______________ Structure _______________

Is the Dry Film Thickness Gage calibrated? .... Yes No.

Air-less Spray?.....Yes No. If "No" air supply clean?..Yes No.

Cleanliness of Steel Surface before Painting

(Please Check With a White Napkin) .... Yes No

Name of Paint Manufacturer _______________

Batch # of paint:________ and the amount ________ gallons used.

Paint Material Approved? .... Yes No.

Is Paint Well Power Mixed .... Yes No

Thinning Approved ..... Yes No

Time/Date of Priming __________

Time between Blasting & Priming __________ Hrs. (Maximum 24 Hours)

Daily Working Ambient Condition:

(If more space is needed, record them on the other side of the paper)

Date						
Time						
Dry Bulb (F)						
Wet Bulb (F)						
Relative Humid.(%)						
Dew Point (F)						
Steel Temp. (F)						
Steel Temp.- Dew Point						
Wind Speed (MPH)						
Is the Ambience OK?(Y/N)						

Weather Comments:____

____

<< Detailed Measurement Data >>> Form 3-2-___

Required Coating Thickness : ____________

Parameter used: n1=n2=10; c1=1; r1=3; c2=4

Required Sample Size : ____10____

Seven reading: 2 on bottom of top flange
3 on web and stiffener
2 on top of bottom flange
1 on vertical edge of bottom flange
2 on bottom of bottom flange.

Use one beam as a "Lot"

x1 : the number of defect in the first sample

x2 : the number of defect in the second sample

Possible Conditions of Acceptance

x1=	x2=
0	
1	
2	0
2	1
2	2

If (x1=0 or 1) then Accept
If (x1= 2) Take Second Sampling
If (x1≥3) Reject

If (x1+x2 ≤ 4) then Accept
If (x1+x2 > 4) Reject

<<Detailed Measurement Data. Please duplicate if necessary>>

Beam/Lot#______ Date of Painting ______		Beam/Lot#______ Date of Painting ______		Beam/Lot#______ Date of Painting ______	
First Sample	Second Sample	First Sample	Second Sample	First Sample	Second Sample
______	______	______	______	______	______
______	______	______	______	______	______
______	______	______	______	______	______
______	______	______	______	______	______
______	______	______	______	______	______
______	______	______	______	______	______
______	______	______	______	______	______
______	______	______	______	______	______
______	______	______	______	______	______
______	______	______	______	______	______
x1=	x2= x1+x2=	x1=	x2= x1+x2=	x1=	x2= x1+x2=
If Visual Inspection OK? Yes No		If Visual Inspection OK? Yes No		If Visual Inspection OK? Yes No	
Accept or Reject		Accept or Reject		Accept or Reject	

<< Detailed Measurement Data >>> Form 3-2-___

Beam/Lot#________ Date of Painting ________	
First Sample	Second Sample
________	________
________	________
________	________
________	________
________	________
________	________
________	________
________	________
________	________
________	________
x1=	x2= x1+x2=
If Visual Inspection OK? Yes No	
Accept or Reject	

Beam/Lot#________ Date of Painting ________	
First Sample	Second Sample
________	________
________	________
________	________
________	________
________	________
________	________
________	________
________	________
________	________
________	________
x1=	x2= x1+x2=
If Visual Inspection OK? Yes No	
Accept or Reject	

Beam/Lot#________ Date of Painting ________	
First Sample	Second Sample
________	________
________	________
________	________
________	________
________	________
________	________
________	________
________	________
________	________
________	________
x1=	x2= x1+x2=
If Visual Inspection OK? Yes No	
Accept or Reject	

Beam/Lot#________ Date of Painting ________	
First Sample	Second Sample
________	________
________	________
________	________
________	________
________	________
________	________
________	________
________	________
________	________
________	________
x1=	x2= x1+x2=
If Visual Inspection OK? Yes No	
Accept or Reject	

Beam/Lot#________ Date of Painting ________	
First Sample	Second Sample
________	________
________	________
________	________
________	________
________	________
________	________
________	________
________	________
________	________
________	________
x1=	x2= x1+x2=
If Visual Inspection OK? Yes No	
Accept or Reject	

Beam/Lot#________ Date of Painting ________	
First Sample	Second Sample
________	________
________	________
________	________
________	________
________	________
________	________
________	________
________	________
________	________
________	________
x1=	x2= x1+x2=
If Visual Inspection OK? Yes No	
Accept or Reject	

<<< Summary of Form 3-2. >>> Form 3-3
(Please duplicate if necessary)

	Beam No. at Span No.	x1=0, 1 Accept x1=2 Take Second Sample x1=3,4,... Reject	x1+x2=1,2,3,4 Accept x1+x2= 5, 6.... Reject	Defect: ? Dry Spray Run, Sag Mud-cracking		Accept this Lot ?	
		x1=	x1+x2=	Yes	No	Yes	No
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							

Appendix 11-3

Field Inspection Forms

(Dec. 22, 1991) Form 1-1

Stage-I **(PRE-INSPECTION FOR <u>FIELD</u> PAINTING)**

Date ______________

Inspected by ______________

District______________ Structure # __________

Contract #____________

Contractor or Sub. ____

1. Is the contract of the project reviewed? .... Yes No
2. Does the contractor submit the paint manufacture instructions? .... Yes No
3. Does the contractor submit the application plan/schedule? .... Yes No
4. Is the traffic control and accessing plan discussed with contractors? .... Yes No
5. Is following equipments ready to use?

Psychrometer	Yes	No
US Weather Bureau Psychometric Tables	Yes	No
Surface Temperature Thermometer	Yes	No
Dry Film Thickness Gage	Yes	No
Testex Micrometer with X-coarse Tape	Yes	No
SSPC Surface preparation Specifications (SSPC 1-89)	Yes	No
NBS Calibration Standard	Yes	No
Tape Measure	Yes	No
Flash Light	Yes	No

Form 2-1-_

Stage-II (**SURFACE PREPARATION INSPECTION FOR FIELD PAINTING**)

Date____________

Inspected by ____________

District______________ Structure # _________
Contract #___________
Contractor or Sub. ______________________________________
Water Wash Cleaned. Yes No. Time/Date of Wash _____________

Solvent Cleaned ... Yes No. Air Cleanliness ... Yes No.
Required Profile:________
Required Surface Cleanliness Grade:___________
Daily Working Report for Profile Measurement
<<First Sampling>>

	Location Beam No.	Profile Reading (mils)	Time/Date of Sand Blast	Visual Cleanliness Checking SSPC Grade of Steel Surface
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

Number of Defect (x1=): ______
If (x1≤1) then Accept
If (x1=2) Take Second Sampling
If (x1≥3) Reject
<<Second Sampling>>

11				
12				
13				
14				
15				
16				
17				
18				
19				
20				

Number of Defect (x2=):____ Total Number of Defect (x1+x2=)____
If (x1+x2 ≤ 4) then Accept
If (x1+x2 > 4) Reject

Form 3-1-___

Stage-III (**PRIMER INSPECTION FOR FIELD PAINTING**)

Date ______________

Inspected by _____________

District_______________ Structure # __________

Contract #____________

Contractor or Sub. ____

Cleanliness of Steel Surface before Painting

(Please Check With a White Napkin) .... Yes No.

Is the Dry Film Thickness Gage calibrated? .... Yes No.

Air-less Spray?.....Yes No. if "No" air supply clean? Yes No.

Name of Paint Manufacturer ________________

Batch # of paint:________ and the amount ________ gallons used.

Paint Material Approved? .... Yes No.

Is Paint Well Power Mixed? .... Yes No.

Thinning Approved ..... Yes No.

Time/Date of Priming ____________________

Time between Blasting & Priming _________ Hrs.(Maximum 24 Hours)

Did the contractor cooperate with INDOT by helping inspectors access the bridge in primer inspection?... Yes No.

Daily Working Ambient Condition: (If more space is needed, record them on the other side of the paper)

Date						
Time						
Dry Bulb (F)						
Wet Bulb (F)						
Relative Humid.(%)						
Dew Point (F)						
Steel Temp. (F)						
Steel Temp.- Dew Point						
Wind Speed (MPH)						
Is the Ambience OK?(Y/N)						

Weather Comments:____

____

<< Detailed Measurement Data >>> Form 3-2-___

Required Coating Thickness : ____________

Parameter used: n1=n2=10; c1=1; r1=3; c2=4

Required Sample Size : ____10____

Seven reading: 2 on bottom of top flange
3 on web
2 on top of bottom flange
1 on vertical edge of bottom flange
2 on bottom of bottom flange.

Use one beam as a "Lot"

x1 : the number of defect in the first sample

x2 : the number of defect in the second sample

Possible Conditions of Acceptance

x1=	x2=
0	
1	
2	0
2	1
2	2

If (x1=0 or 1) then Accept
If (x1= 2) Take Second Sampling
If (x1≥3) Reject

If (x1+x2 ≤ 4) then Accept
If (x1+x2 > 4) Reject

<<Detailed Measurement Data. Please duplicate if necessary>>

Beam/Lot#________ Date of Painting ________		Beam/Lot#________ Date of Painting ________		Beam/Lot#________ Date of Painting ________	
First Sample	Second Sample	First Sample	Second Sample	First Sample	Second Sample
________	________	________	________	________	________
________	________	________	________	________	________
________	________	________	________	________	________
________	________	________	________	________	________
________	________	________	________	________	________
________	________	________	________	________	________
________	________	________	________	________	________
________	________	________	________	________	________
________	________	________	________	________	________
________	________	________	________	________	________
x1=	x2= x1+x2=	x1=	x2= x1+x2=	x1=	x2= x1+x2=
If Visual Inspection OK? Yes No		If Visual Inspection OK? Yes No		If Visual Inspection OK? Yes No	
Accept or Reject		Accept or Reject		Accept or Reject	

<< Detailed Measurement Data >>> Form 3-2-___

Beam/Lot#________ Date of Painting ________	
First Sample	Second Sample
x1=	x2= x1+x2=
If Visual Inspection OK? Yes No	
Accept or Reject	

Beam/Lot#________ Date of Painting ________	
First Sample	Second Sample
x1=	x2= x1+x2=
If Visual Inspection OK? Yes No	
Accept or Reject	

Beam/Lot#________ Date of Painting ________	
First Sample	Second Sample
x1=	x2= x1+x2=
If Visual Inspection OK? Yes No	
Accept or Reject	

Beam/Lot#________ Date of Painting ________	
First Sample	Second Sample
x1=	x2= x1+x2=
If Visual Inspection OK? Yes No	
Accept or Reject	

Beam/Lot#________ Date of Painting ________	
First Sample	Second Sample
x1=	x2= x1+x2=
If Visual Inspection OK? Yes No	
Accept or Reject	

Beam/Lot#________ Date of Painting ________	
First Sample	Second Sample
x1=	x2= x1+x2=
If Visual Inspection OK? Yes No	
Accept or Reject	

<<< Summary of Form 3-2. >>> Form 3-3

(Please duplicate if necessary)

	Beam No. at Span No.	x1=0, 1 Accept x1=2 Take Second Sample x1=3,4,... Reject	x1+x2=1,2,3,4 Accept x1+x2= 5, 6.... Reject	Defect: ? Dry Spray Run, Sag Mud-cracking		Accept this Lot ?	
		x1=	x1+x2=	Yes	No	Yes	No
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							

Form 4-1

Stage-IV
(TOP-COATING / IMMEDIATE-COATING INSPECTION FOR FIELD PAINTING)

Date ______________

Inspected by _____________

District _______________ Structure # __________

Contract #____________

Contract or Sub. ____

Cleanliness of Steel Surface before Painting

(Please Check With a White Napkin) .... Yes No

Is the Dry Film Thickness Gage calibrated? .... Yes No.

Air-less Spray?....Yes No. If "No" air supply clean? Yes No.

Name of Paint Manufacturer ________________

Batch # of paint:___________ and its amount is __________ gallons.

Paint Material Approved? .... Yes No.

Is Paint Well Power Mixed? .... Yes No.

Thinning ..... Yes No.

Viscosity Cup Reading ____second (Required _____ second)

Time/Date of Top-Coating ____________

Time between Priming & Top-Coating ____________

Daily Working Ambient Condition: (If more space needed, record data on the other side of this paper)

Date						
Time						
Dry Bulb (F)						
Wet Bulb (F)						
Relative Humid.(%)						
Dew Point (F)						
Steel Temp. (F)						
Steel Temp.- Dew Point						
Wind Speed (MPH)						
Is the Ambience OK?(Y/N)						

Weather Comments:____

____

Did the contractor cooperate with INDOT by helping inspectors access the bridge? .... Yes No

<< Detailed Measurement Data for **Field** Inspection>> Form 4-2-___

Required Coating Thickness : ____________

Parameter used: n1=n2=10; c1=1; r1=3; c2=4

Required Sample Size : ____10______

Seven reading: 2 on bottom of top flange
3 on web
2 on top of bottom flange
1 on vertical edge of bottom flange
2 on bottom of bottom flange.

Use one beam as a "Lot"

x1 : the number of defect in the first sample

x2 : the number of defect in the second sample

Possible Conditions of Acceptance

x1=	x2=
0	
1	
2	0
2	1
2	2

If (x1=0 or 1) then Accept
If (x1= 2) Take Second Sampling
If ($x1 \geq 3$) Reject

If ($x1+x2 \leq 4$) then Accept
If ($x1+x2 > 4$) Reject

<<Detailed Measurement Data. Please duplicate if necessary>>

Beam/Lot#________ Date of Painting ________		Beam/Lot#________ Date of Painting ________		Beam/Lot#________ Date of Painting ________	
First Sample	Second Sample	First Sample	Second Sample	First Sample	Second Sample

x1=	x2= x1+x2=	x1=	x2= x1+x2=	x1=	x2= x1+x2=
If Visual Inspection OK? Yes No		If Visual Inspection OK? Yes No		If Visual Inspection OK? Yes No	
Accept or Reject		Accept or Reject		Accept or Reject	

<<Detailed Measurement Data for **Field** Inspection>> Form 4-2-___

Beam/Lot#_______ Date of Painting _______	
First Sample	Second Sample
x1=	x2= x1+x2=
If Visual Inspection OK? Yes No	
Accept or Reject	

Beam/Lot#_______ Date of Painting _______	
First Sample	Second Sample
x1=	x2= x1+x2=
If Visual Inspection OK? Yes No	
Accept or Reject	

Beam/Lot#_______ Date of Painting _______	
First Sample	Second Sample
x1=	x2= x1+x2=
If Visual Inspection OK? Yes No	
Accept or Reject	

Beam/Lot#_______ Date of Painting _______	
First Sample	Second Sample
x1=	x2= x1+x2=
If Visual Inspection OK? Yes No	
Accept or Reject	

Beam/Lot#_______ Date of Painting _______	
First Sample	Second Sample
x1=	x2= x1+x2=
If Visual Inspection OK? Yes No	
Accept or Reject	

Beam/Lot#_______ Date of Painting _______	
First Sample	Second Sample
x1=	x2= x1+x2=
If Visual Inspection OK? Yes No	
Accept or Reject	

<<< Summary of Form 3-2. for **Field** Inspection>>> Form 4-3
(Please duplicate if necessary)

	Beam No. at Span No.	x1=0, 1 Accept x1=2 Take Second Sample x1=3,4,... Reject	x1+x2=1,2,3,4 Accept x1+x2= 5, 6.... Reject	Defect: ? Dry Spray Run, Sag Mud-cracking		Accept this Lot ?	
		x1=	x1+x2=	Yes	No	Yes	No
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							

Appendix 11-4

Stratified Double Sampling Scheme

Stratified Sampling Scheme

The stratification for a sampling scheme could be a whole bridge or part of the project. For reducing the risk or conforming the process of the painting construction, a bridge could be divided into several lots, then decisions of acceptance or rejection are independent within each lot.

For Shop Painting

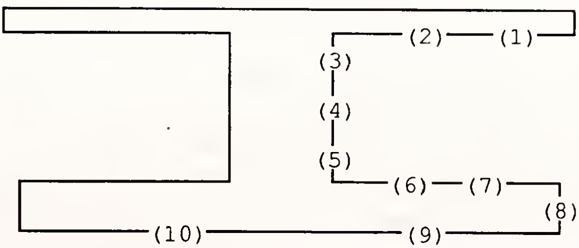
A beam is the natural geometry which can be used to set up the sampling scheme. One beam is treated as a lot. However, to reduce the sample size and minimize the deterioration of the accurate for the acceptance decision, the double sampling system is applied shown as follows:

<<Reduced Sample Size by Using Double Sampling: n1=n2=10>>
Required Sample Size : ____10____
Parameter used:

- n1=n2=10: Sample size for both the first ans second sampling
- c1=1 : Acceptable number for first sample
- r1=3 : Rejectable number for first sample
- c2=4 : Rejectable number for second sample
- x1 : nonconforming number of first samplng
- x2 : nonconforming number of second samplng

If the nonconforming number x1 equal to or less than c1(=1), the lot is accepted. If x1≥r1(=3), reject the lot without taking the second sampling. If the nonconforming number is 2 (c1<x1<r1), second sample of size 10 is needed to be taken on other areas within the same lot. If the second sampling taken and the total nonconforming number x1+x2≤c2(=4), accept this (lot). Otherwise, reject this lot. Please see the flow chart in Appendix 11-7.

The sample sizes equal to 10 in both the first and second sampling. These 10 readings should be distributed to each area on the webs and flange as the following figure shows.



Seven reading: 2 on bottom of top flange
3 on web/stiffener
2 on top of bottom flange
1 on vertical edge of bottom flange
2 on bottom of bottom flange.

Field Painting

The sampling scheme for filed painting is similar to shop painting. However, in the field, the contractors usually paint the bridges by crossing the beam (along the traffic lanes). Thus, one beam within the length of one day's production is considered as a lot. Inside each lot, the following sampling plan is taken.

Required Sample Size : 10

Parameter used:

n1=n2=10 : Sample size for both the first ans second sampling c1=1 : Acceptable number for first sample

r1=3 : Rejectable number for first sample

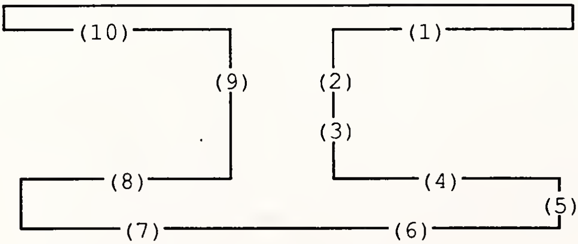
c2=4 : Rejectable number for second sample

x1 : nonconforming number of first samplng

x2 : nonconforming number of second samplng

If the nonconforming number x1 equal to or less than c1=1, the lot is accepted. If $x1 \geq r1=3$, reject the lot without taking the second sampling. If the nonconforming number is 2 ($c1<x1<r1$), second sample of size 10 is needed to be taken on other areas within the lot. If the second sampling taken and the total nonconforming number $x1+x2 \leq c2=4$, accept this (lot). Otherwise, reject this lot. Please see the flow chart in appendix 11-7.

The sample sizes equal to 10 in both the first and second sampling. These 10 readings should be distributed to each area on the webs and flange as the following figure shows.



Seven reading: 2 on bottom of top flange
3 on web/stiffener
1 on top of bottom flange
1 on vertical edge of bottom flange
2 on bottom of bottom flange.

For one beam, the length used to set up a lot is the length where the painters paint in one day.

Possible Conditions of Acceptance for Two Proposed Double Sampling Plans (Sample Sizes of 7 or 10):

There are two double sampling proposed and their parameters are show in the following tables.

n1=n2=7 c1=0 r1=3 c2=3	
Acceptable Quality Level (AQL) = 10% Rejectable Quality Level (RQL) = 47% $\alpha = \beta = 5\%$	
x1=	x2=
0	
1	0
1	1
1	2
2	0
2	1

n1=n2=10 c1=1 r1=3 c2=4	
Acceptable Quality Level (AQL) = 9% Rejectable Quality Level (RQL) = 42% $\alpha = \beta = 5\%$	
x1=	x2=
0	
1	
2	0
2	1
2	2

Basic Requirement for Random Sampling

When inspectors take samples, the sample must be randomly distributed along the lot. Basic requirements for taking sample are:

(1) Contractors should not know in which area inspectors might check the quality.

(2) Inspectors will need to check spots randomly, but not depending on conveniences or preferences.

(3) Clear documents of the measurements are necessary which can help to avoid legal problems in the future.

(4) There should be an equal opportunity for each spot to be sampled in a lot.

(5) There should be a hold point after sand blasting, priming and top-coating. And then, the contractors should notify the inspectors to inspect and approve the project.

Appendix 11-5

Calibration Method

of

SSPC-PA2

Generally, there are two main methods used to calibrate a DFT gage. They are stated in SSPC-PA2 as follows:

Type-I

By using the National Bureau of Standards Plates, first, adjust the instrument to read the thickness stated on the calibration blocks in the desired range of use. Next, take the gage reading the bare, non-coated substrate after blasting cleaning (or other surface preparation). The instrument will generally read between one or two tenths of a mils up to 1 mils or more over the bare steel. Therefore any coating thickness reading taken must be corrected by this bare steel reading in order to determine the coating thickness above the peaks of profile. (SSPC Manual, 1989, Vol.1 p.200)

Type-II

Calibration of the electrically operated instruments is accomplished by placing the instrument probe directly on the bare steel substrate (after surface preparation) and adjusting the designated knob (i.e. "zero") so that the meter reads "0". Next, place the calibration shim of desired thickness on the steel and adjust the appropriate knob so that the meter indicates the correct shim thickness. Any effect of surface roughness is calibrated into the instrument because it was adjusted over the bare steel, thus eliminating the need for magnetic base reading correction factor (SSPC Manual, 1989, Vol.1 p.201).

Appendix 11-6

Air Cleanliness Test Method

of

SSPC

The compressed air used for blast cleaning, blow down, and spray application should be checked for contaminates. Adequate moisture and oil traps should be used on all lines to assure that the air is sufficiently dry and oil-free so it does not interfere with the quality of the work.

A simple test for determining air cleaning requires holding a clean white piece of blotter paper approximately 18 inches from the air supply downstream form moisture and oil separators. The air is permitted to blow on the blotter paper for a few minutes followed by an inspection of sign of detrimental amounts of moisture or oil contamination on the blotter. (SSPC Manual, 1989, Vol.1 p.188)

Obviously, if there is no discoloration on the blotter, the quality of the air is excellent, while streams of moisture and oil running down the sheet indicate unsatisfactory air. By using the blotter paper, one can make his own judgements as to the air quality.

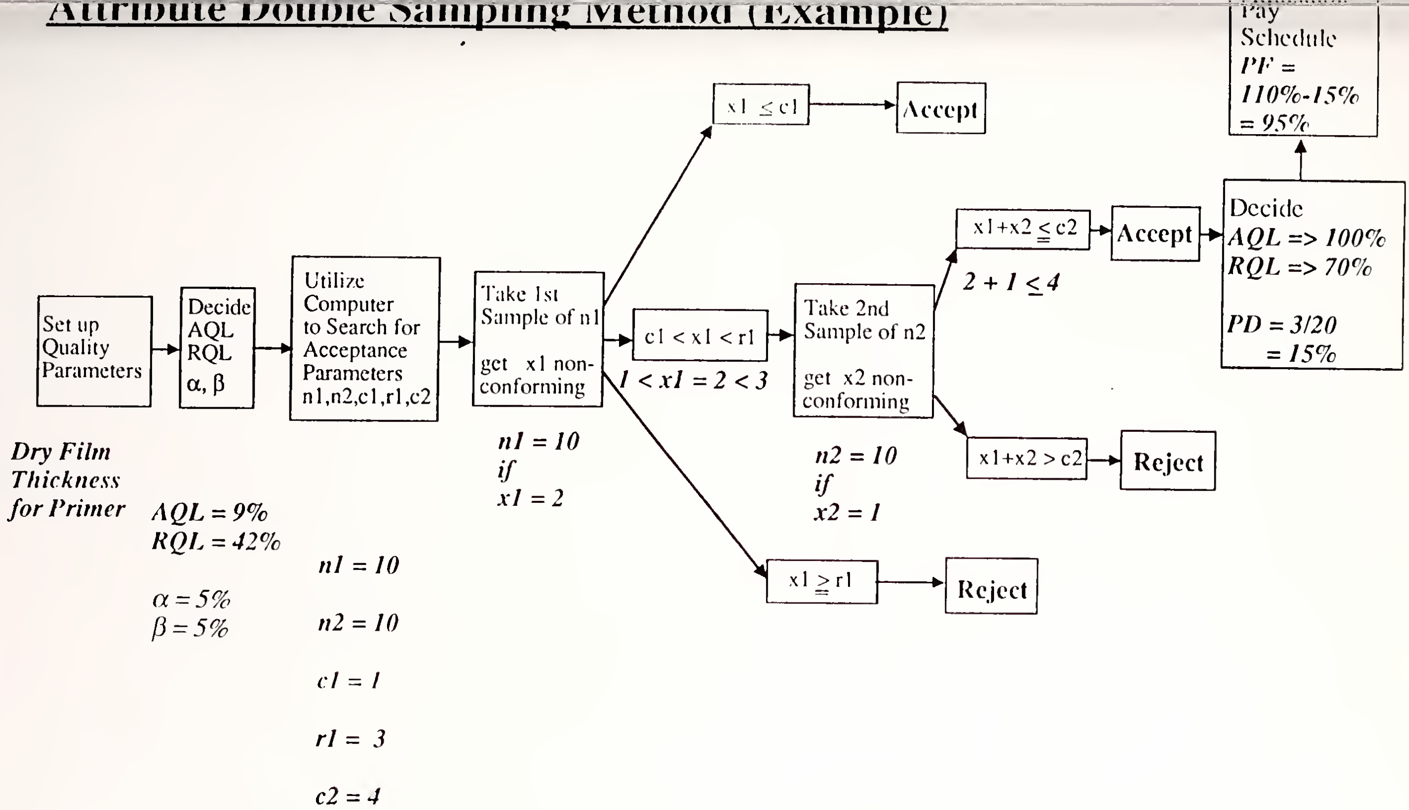
Appendix 11-7

Flow Chart

for

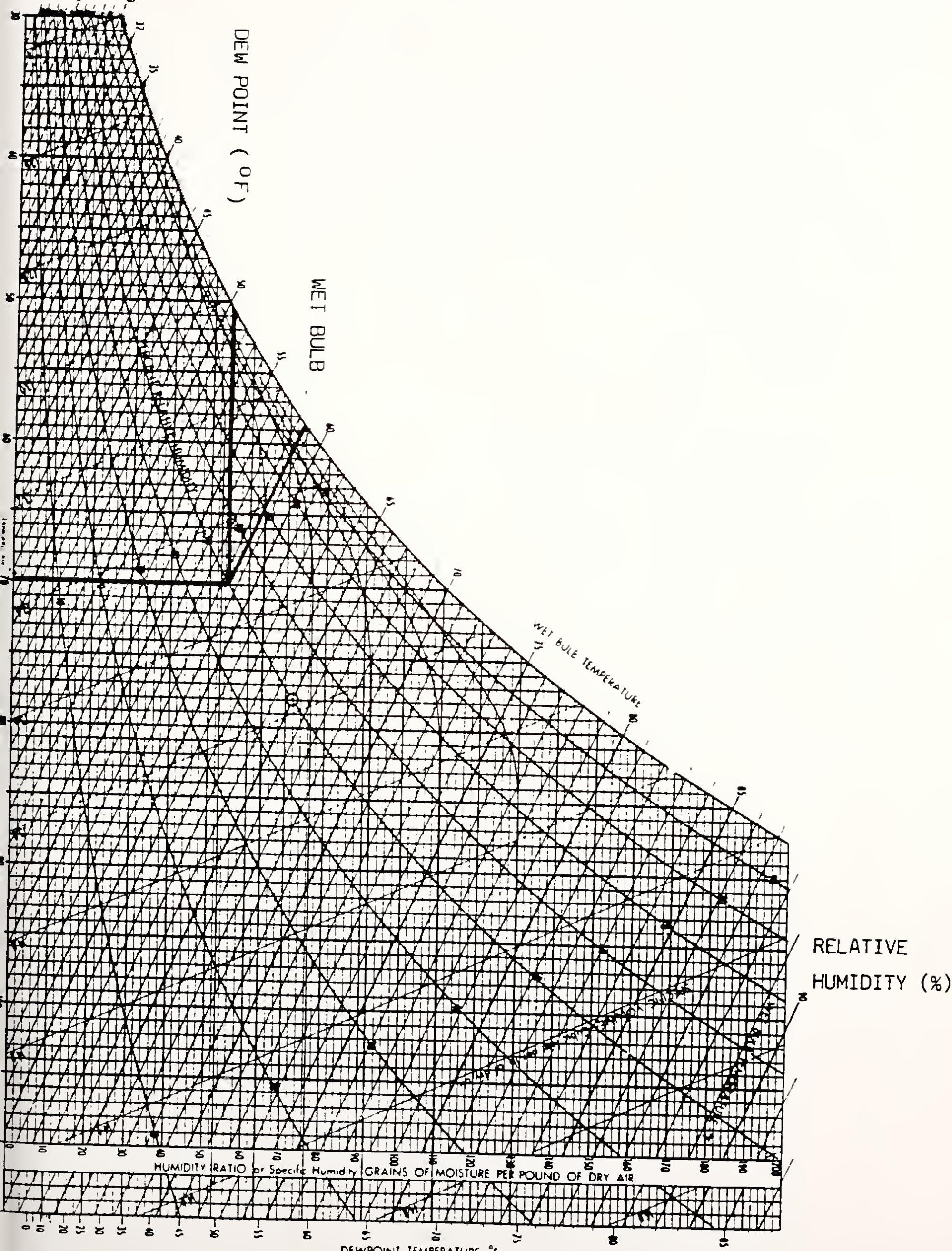
Double Sampling Plan

Attribute Double Sampling Method (Example)



Appendix 11-8

US Weather Bureau Psychometric Monograph


DEW POINT (°F)
WET BULB
WET BULB TEMPERATURE
RELATIVE HUMIDITY (%)
HUMIDITY RATIO or Specific Humidity GRAINS OF MOISTURE PER POUND OF DRY AIR
DEWPOINT TEMPERATURE -°F

COVER DESIGN BY ALDO GIORGINI